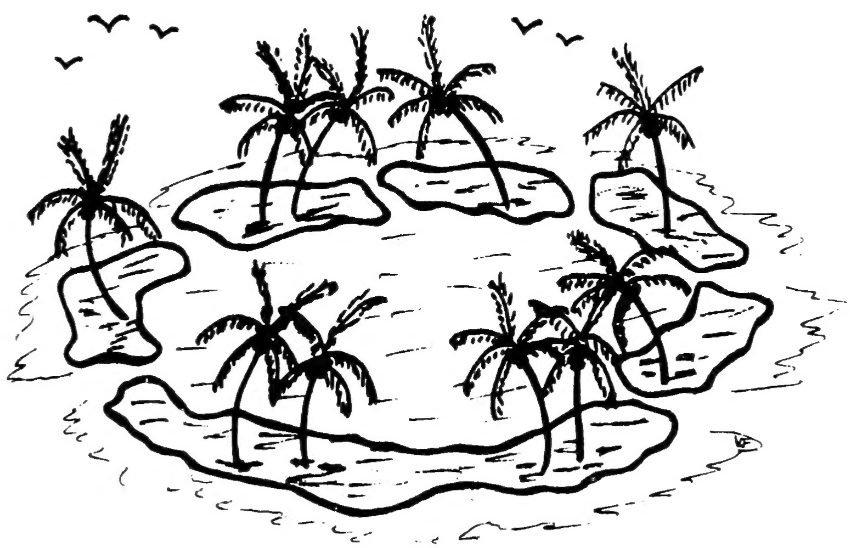
No. 86 February 28, 1962

ATOLL RESEARCH BULLETIN

Geography and land ecology of Clipperton Island

by

Marie-Hélène Sachet



Issued by
THE PACIFIC SCIENCE BOARD
National Academy of Sciences—National Research Council
Washington, D.C., U.S.A.

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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past fourteen years.

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Washington 25, D. C., U.S.A.

CONTENTS

PREFACE

During the International Geophysical Year, Scripps Institution of Oceanography, a branch of the University of California, organized several research cruises in the Pacific, as part of the world-wide program. Several previous cruises had called attention to Clipperton Island, and during the Doldrums Expedition of the summer of 1958 it was decided to study the biogeography of this little-known island. A group of 13 persons were left on the island by the Research Vessel Spencer F. Baird on August 7, 1958 and were taken aboard again on August 26, except for four who remained until September 25 to continue their studies of sharks. I had the great good fortune to be one of the group and to study plant life on the island. In addition I made observations on the land fauna and geology, and some collections of animals, soils and rocks.

It will not be easy to thank adequately the many persons who have contributed to the success of my work on Clipperton. In the first place of course I want to express my gratitude for this unique opportunity to Scripps Institution of Oceanography and to its Director, Dr. Roger Revelle. I owe much also to Dr. Carl Hubbs, from whom the invitation was received, to Mr. John A. Knauss, leader of the Doldrums Expedition, to the late Conrad Limbaugh, chief of the Clipperton field party, to all my companions in the field and to the Master and crew of the Baird. Our visit could not have taken place without the authorization of the French Government, and without the intervention of Dr. Jean Delacour, then Director of the Los Angeles County Museum and Professor Roger Heim, Director of the Muséum National d'Histoire Naturelle in Paris, who helped procure this authorization. The French Embassy and the Office of the Naval Attaché in Washington were also very helpful.

For permitting me to join the expedition and encouraging me to work up the material, I wish to thank my superiors in the U. S. Geological Survey and in the Pacific Science Board, National Academy of Sciences--National Research Council. The Academy also provided very welcome help in the form of a grant from the Joseph Henry Fund. I cannot name here all the persons who have contributed identifications, analyses, and suggestions and to whom I am deeply grateful. They will be mentioned in the course of the paper. In assembling bibliographic material and photographs I have benefited from the facilities of many individuals and several organizations: the U. S. Navy's Naval History Division, Hydrographic Office and Office of Naval Research, the Service Historique de la Marine Nationale of France, the U. S. Weather Bureau, the U. S. National Museum, the U. S. National Archives, the Library of Congress, the California Academy of Sciences, and the Bibliothèque Nationale of France.

Miss Evelyn L. Pruitt, Head of the Geography Branch, Office of Naval Research, gave me much help in searching for photographs and documents in the U. S. Navy files. Messrs. E. C. Allison, Ted Arnow, Willard Bascom, A. I. Cooperman, A. S. Hambly, Lester F. Hubert, W. L. Klawe, John Knauss, H. S. Ladd, Conrad Limbaugh, W. E. Malone, H. E. Maude, C. S. Ramage, Waldo Schmitt and R. E. Snodgrass gave me unpublished information, lent me photographs and documents, or read and criticized parts or all of the manuscript. Mr. V. A. Rossi gave me advice and help with the illustrations, and Dr. Gilbert Corwin examined the samples of volcanic rocks.

I wish to make special mention of Mr. Obermüller, Géologue en Chef de la France d'Outre-Mer, who worked on Clipperton a few months before I went there and gave me copies of his reports even before their publication, as well as samples of his rock collections.

Finally I wish to express my appreciation and gratitude to Dr. F. R. Fosberg who helped and encouraged me in every step of this work.

The appearance of this paper has been delayed by various circumstances, as has that of a more extensive and profusely illustrated memoir on Clipperton (Sachet, in press).

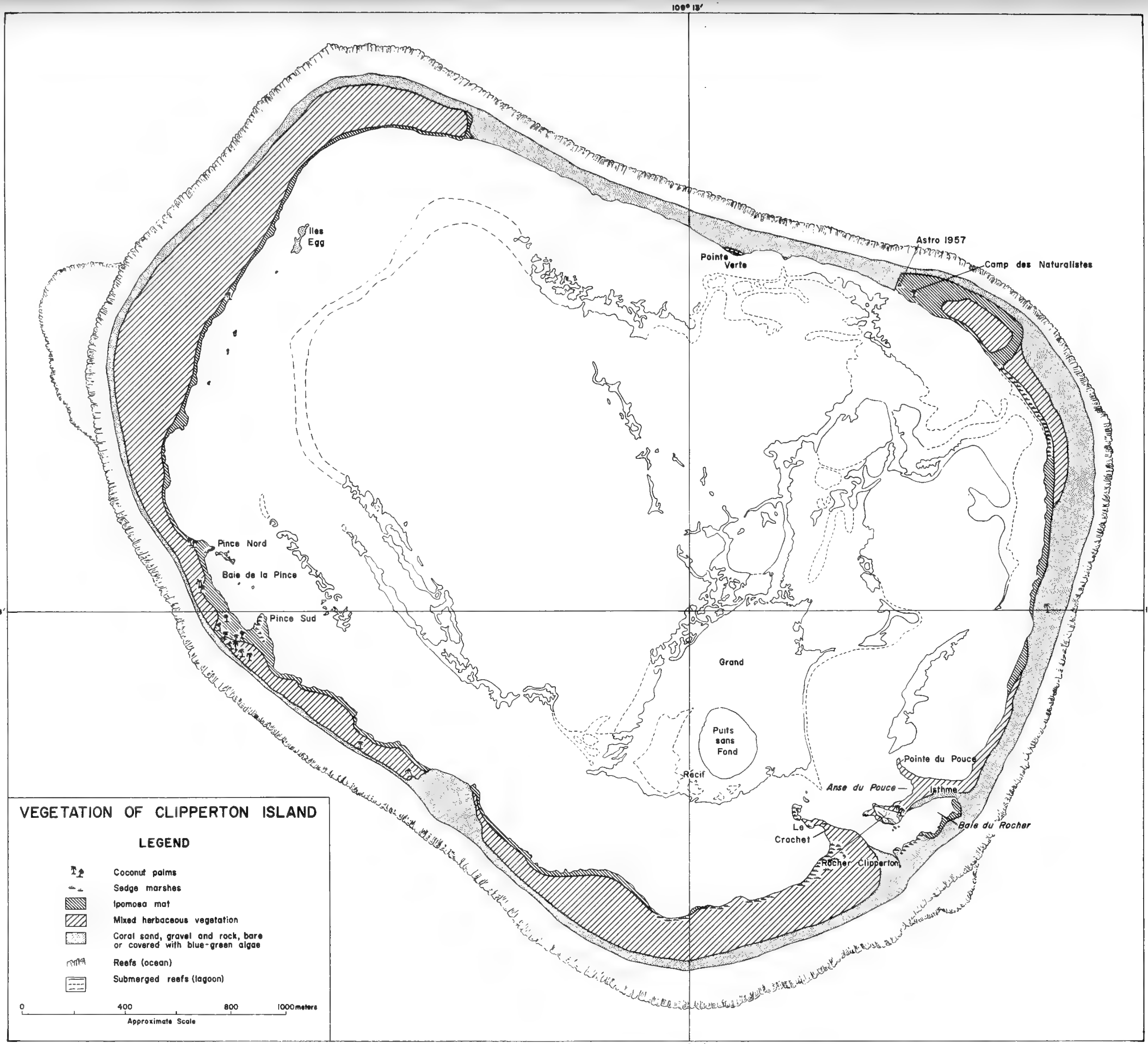

109° 13′
10° 18′
Iles Egg
Pointe Verte
Astro 1957
Camp des Naturalistes
Pince Nord
Baie de la Pince
Pince Sud
Grand
Puits sans Fond
Récif
Pointe du Pouce
Anse du Pouce
Isthme
Baie du Rocher
Le Crochet
Rocher Clipperton
VEGETATION OF CLIPPERTON ISLAND
LEGEND
Coconut palms
Sedge marshes
Ipomoea mat
Mixed herbaceous vegetation
Coral sand, gravel and rock, bare or covered with blue-green algae
Reefs (ocean)
Submerged reefs (lagoon)
0
400
800
1000 meters
Approximate Scale

Fig. 1

INTRODUCTION

Geographic location, general description

Clipperton Island (Fig. 1), one of the few oceanic islands in the Eastern Pacific, excites the interest and curiosity of naturalists especially because it is the only coral island in that part of the ocean. The nearest atoll, Pukapuka in the Eastern Tuamotus, lies 2300 nautical miles to the southwest.

Here are some other figures that will give an idea of the isolation of Clipperton, the coordinates of which are 10°18'N and 109°13'W (adjusted position for Astro 1957, a monument placed by the U. S. Hydrographic Office on the northeast side: 10°18' 41"N, 109°12' 34"W). The nearest land is the Mexican west coast, 600 nautical miles to the north-north-east. The nearest islands to the north are the Revillagigedo Islands of which Soccoro is 530 miles from Clipperton. The Galapagos lie 1300 miles to the southeast and Easter Island 2250 miles due south.

In its general form, Clipperton is a low closed ring of coral limestone, but the island does not exactly qualify as an atoll as a small volcanic rock rises at the end of a short peninsula in the lagoon. This type of island has been called an "almost-atoll," but this category is not very natural and formations have been placed in it which may have nothing in common beyond the fact that they include both coral and volcanic features. For the purposes of this description it seems practical to consider the island as an atoll, the only one in the eastern third of the Pacific Ocean. In area, Clipperton Rock is very small, compared to the coral ring, and observations so far seem to indicate that it has little influence on the ecology of the island. No macroscopic plants grow on the Rock, except for some lichens.

The coral ring is somewhat egg-shaped and symmetrical along a northwest-southeast axis. This axis falls a little north of the Rock, which is close to the southeast coast of the island. The ring is continuous and encloses a brackish lagoon. Only a small minority of atolls are closed and few of these have a rim as narrow as Clipperton's, around such a comparatively large lagoon. The greatest dimension of the atoll, along the NW-SE axis is 4 km and the circumference of the atoll ring about 12 km. The emerged land strip is widest along the northwest coast, with a maximum width of about 400 m in the west corner. The average width is under 200 m, and in narrow places it is much less. In August 1958 the northern part of the northeast coast measured only 45 m from lagoon to ocean. That area of the land was also the lowest, rising only 0.65 m above estimated mean high tide level. Generally the ground slopes up from the ocean to the tops of the beaches or boulder ridges, and gently down again toward the lagoon so that the highest point of any given ocean-lagoon section is the crest of the outer beach or boulder ridge. This crest varies in altitude, reaching a maximum of about 4 m. The volcanic Clipperton Rock listed on charts as 29 m high, is visible from every part of the atoll. From a small boat in the lagoon the land rim is visible all around, but appears very low. In fact one has the impression of floating

in an immense saucer full of water and with a very low rim. Oceanward, the land rim is surrounded by a reef-flat lying at about low tide level. On the ocean side, the outline of the atoll is practically featureless and smooth. The lagoon shores are more irregular, with several small peninsulas and bays. Half way along the northeast side the small triangular Green Point (Pointe Verte) juts into the lagoon (see map). On the southeast side, Clipperton Rock (Rocher Clipperton) rises at the end of a small peninsula, the Isthmus (Isthme); Thumb Point (Pointe du Pouce) extends northward from the Isthmus, separated from the Rock by Thumb Cove (Anse du Pouce). Between the Isthmus and the landstrip, the lagoon forms an arm called Rock Bay (Baie du Rocher). Just west of the Rock, another peninsula, The Hook (Le Crochet), stretches northwestward into the lagoon.

The abandoned quonset village and the large coconut grove on the southwest side of the atoll are located along a small bay, Pincer Bay (Baie de la Pince) formed by two peninsulas, North and South Pincers (Pince Nord and Pince Sud). Other recognizable features are the 5 Egg Islands (Iles Egg) along the northwest side, and the U. S. Hydrographic monument (Astro 1957) and small group of coconut palms marking Naturalists' Camp (Camp des Naturalistes) near the East corner of the island.

Historical sketch*

Clipperton Island is named after an English buccaneer, John Clipperton, who is reported to have seen it in 1705. Clipperton, who was travelling with the famous privateer and naturalist William Dampier, deserted and stole a Spanish prize bark in which he crossed the Pacific, a remarkable feat. There is no account of this voyage during which the island is supposed to have received its name (Burney 1816), and in the description of Clipperton's second voyage (Betagh 1728) no mention is made of the earlier discovery, but the name was indicated on maps about 1730 or 1735 (Moll).

Various authors (Toniolo 1919, Mexico [1911]) have suggested that Spanish navigators may have seen the island earlier, in the 16th or 17th centuries, or even that Magellan may have discovered it in 1521 (Nunn 1934). The island would then be identical with Medaños and San Pablo (Magellan). Historically, such considerations are of great interest but as far as our scientific knowledge of the island is concerned they are immaterial, as it is quite unlikely that ancient descriptions will come to light.

Our knowledge of the island, and the extensive literature concerning it, then begin in 1711. On April 3, Good Friday, two small French vessels, the _Princesse_ and the _Découverte_, who had left Brest together in 1708, met with an unknown island which was named Ile de la Passion. The Captain of the _Découverte_, Michel du Bocage, and a passenger in the _Princesse_, Mr. de Prudhomme described the new island, the one in his log and the other

* For a more detailed treatment see Sachet 1960.

in his diary. Their discovery was first mentioned in print in 1725 (La Barbinais Le Gentil), while their accounts were published in extenso in a French report (France 1912). The original documents are kept in the French National Archives.

Mr. du Bocage described Clipperton as "A large Rock, cragged and jagged, at the south point of a very flat island..." The northeast side, "sandy with some brush and a dried-up tree on the north-east point, was but a very narrow tongue of land. The center of the island was a large lake reaching from one side to the other. The west side appeared to have some low brush with soil and some rock but very low, although a little higher than the east side." Mr. de Prudhomme also described the very low sandy island, without any trace of inhabitants, unwooded except for some very low bushes, and with some dead trees on the sea shore "as if they had been thrown up by the currents."

These brief accounts are remarkable in that they describe Clipperton much as it appears today from aboard ship, except for the recently added coconut trees and various traces of human activity.

There can be no doubt that Ile de la Passion is the island now called Clipperton. The coordinates given in 1711 were:

Du Bocage	10°28'N, 263°50'	(113°3'W Greenwich)
De Prudhomme	10°18-19'N, 268°11'	(108°27'W)

(From the latest observations, the coordinates are 10°18'N, 109°13'W).

Over a hundred years later (1832), an American sea-captain, Morrell, described the island as he saw it in August 1825: "It is low all around near the water, but a high rock rises in the centre, which may be seen at the distance of six leagues..." As far as known, Morrell and his men were the first to land on Clipperton.

Except for a small sketch map, poorly oriented, which Mr. de Prudhomme mentions and which is kept with his diary and reproduced in the French report (1912), Clipperton Island was first mapped by Sir Edward Belcher and the map published by the British Admiralty in 1849. In May 1839, when Belcher visited it, the island was (Belcher 1843): "a very dangerous low lagoon island, destitute of trees, with a high rock on its southern edge, which may be mistaken for a sail .../The belt of land/ literally constitutes two islands, formed by its two openings ..." (See fig.4,facing p.69).

A few years later, a French ship owner, Mr. Lockhart, arranged to take possession of the unclaimed island for France and to exploit its phosphate deposits. Thus it came about that in 1858, one of Mr. Lockhart's merchant vessels, l'Amiral, Captain Detaille, Master, arrived at Clipperton. Lt. Victor Le Coat de Kerveguen, who had received a special commission for the purpose, took possession of the island for the Second Empire on November 17, 1858. The Amiral then proceeded to Honolulu where the necessary papers were filed to announce to the world that the island was now a French possession. Le Coat de Kerveguen took notes on what was observed on Clipperton and his manuscripts, sketches and maps are reproduced

in the French report (1912). In 1858 the coral rim was closed, the lagoon salty, there was no vegetation, but great numbers of sea birds. Some soil samples were collected, but exploitation of the phosphate deposits did not seem worth while and was not then undertaken.

In August 1861 (Pease 1868) a young American, Lt. Griswold, who later lost his life at Antietam, visited Clipperton Island and found it uninhabited, covered with birds but devoid of vegetation. The lagoon was closed, its water fresh and full of a water plant which he collected. This first botanical specimen from Clipperton was sent to the California Academy of Sciences in San Francisco and lost in the 1906 fire.

Just who discovered phosphate deposits on Clipperton Island is obscure. They were known to Lockhart in 1857, and Griswold was on a phosphate exploration trip. In 1892 Frederic W. Permien made several trips to Clipperton to survey the deposits and in 1893 the Oceanic Phosphate Company of San Francisco sent two men, Jensen and Hall, to survey the island and begin exploitation (Anon. 1893). The observations of Jensen, and his excellent sketch-map are reproduced by Agassiz (1894, pp. 174-175). Jensen had collected a piece of the volcanic rock, which was identified as a trachyte. At the same time, A. Churchill Fisher made observations on tides (U. S. National Archives). W. C. Erratt, of the Schooner Anna of San Francisco, surveyed the phosphatic deposits probably in 1897, and his map is available in the Archives. Also in 1897, P. J. Hennig (Anon 1897) prepared a map, which he forwarded to the U. S. Hydrographic Office. It was promptly published as an H. O. Chart (no. 1680), replacing the charts based on Belcher's sketch, and remaining in use by all navigators until the French survey of 1935.

Exploitation of the Clipperton phosphate proved difficult and not very profitable, and several companies were to attempt it one after the other before the island was abandoned during World War I. When the French war ship Duguay-Trouin arrived at Clipperton in Nov. 1897, a small camp was discovered with three employees of the Oceanic Phosphate Co., who hoisted the U. S. flag. France protested, the United States announced that they had no claim on the island and Mexico joined the excitement. The Duguay-Trouin was hardly out of sight when a Mexican gunboat, the Democratá, arrived (Dec. 13, 1897). Here started a diplomatic conflict which was to last until 1931, when King Victor-Emmanuel III of Italy awarded the island to France, and which has become a text-book case for students of diplomacy and International Law. France and Mexico had agreed to submit the case to the monarch's arbitration in 1909, and both countries published historical reports (Mexico [1911], France 1912) to present their cases. They are valuable documents, the French one especially, as it includes all the texts describing the island to date, some of them unpublished until then.

During this period, Mexico continued to lease the phosphate deposits of the island to various companies including the Pacific Islands Company Ltd. of John Arundel. Also during that time, several naturalists visited the island and made geological and zoological collections, among them John Arundel in 1897 (Wharton 1898, Garman 1899), Snodgrass and Heller in 1898, R. H. Beck in 1901 (Beck 1907), and the California Academy of

Sciences expedition in 1905 (Slevin 1931). Casual visitors added specimens, especially shells, to the collections of Clipperton animals. For instance a group of shells in the U. S. National Museum was received in 1897 from Mr. Arnheim, a ship chandler who had obtained them from sailors.

In 1906 a light was built on top of the Rock, but during World War I, the island was abandoned in a dramatic chapter of its history, and was forgotten. There are quite a few accounts of it for the period 1893-1906, but hardly any information between 1917 and 1935. According to a letter in the U. S. National Archives, several men from the Schooner Ethel M. Sterling from San Pedro landed on Clipperton on January 5, 1929, after several days of bad weather kept them on board ship off the island, and they collected samples of guano and lagoon water. The research vessel Velero III (Fraser 1943) stopped at Clipperton on January 6, 1934, but landing was impossible, although some biological specimens were dredged a short distance off shore. In January 1935, the French training ship Jeanne d'Arc after several visits when landing was impossible, came back to Clipperton, and a group of officers and midshipmen succeeded in making a landing on January 26. They drew a map, wrote descriptions of the island, and collected some plant and rock samples (Lacroix 1939, Gauthier 1949). The ship's seaplane took some photographs. A bronze plaque sealed on the east face of the Rock commemorated the visit and established French ownership.

The next well-known visit was that of President F. D. Roosevelt in July 1938, during a cruise on the USS Houston. Dr. Waldo Schmitt of the U. S. National Museum, who had been invited to travel with the President as expedition naturalist, landed on Clipperton for a few hours and made some very valuable collections of plants and animals which were described in a series of papers (Smithsonian Misc. Coll., 1939-1942).

During the second World War, Clipperton is said to have been visited by Japanese submarines; in 1943 and 1944, the U. S. Navy made several reconnaissances of the island and the famous Australian pilot Captain Sir P. G. Taylor landed his seaplane in the lagoon. Such visits resulted in valuable descriptions (Byrd 1943, Taylor 1948) and photographs. In Dec. 1944, a small U. S. Weather Station was established. The ship (LST 563) bringing most of the material for its construction struck the reef, and its great rusted carcass, battered and much dismantled was still a conspicuous landmark near the landing point on the northeast side in August 1958, and served as a breakwater for small boats effecting a landing. Rusting landing craft, fuel tanks and ammunition were scattered nearby across the land strip. The weather station lasted until October 1945, and its ruins are still recognizable as an abandoned quonset village in the southwest coconut grove, the roads marked by tracked vehicles during that period can still be followed most of the way around the island.

Since the end of World War II, French Navy ships have been visiting the island regularly (Goua 1952, Bourgau 1954) and when landing turned out to be possible, markers have been attached to the base of the Rock. In 1958, there were 4 such commemorative tablets. During the fifties, scientific groups from various institutions stopped at Clipperton and made

observations or collections: the U. S. Navy Electronics Laboratory in May 1952 (Hertlein and Emerson 1953), Scripps Institution of Oceanography in Dec. 1954, and Oct. 1956 (Dawson 1957, Hertlein and Emerson 1957), and U. S. Hydrographic Office, Nov. 1957. This last group was making astronomical and geophysical observations, and determining the exact position of the island. A French Navy officer and Mr. A. G. Obermüller, chief geologist of the France d'Outre-Mer accompanied the American geophysicists. The geological collections have been described in an important report (Obermüller 1959). Another valuable result of this expedition is a collection of photographs taken from a helicopter. In May 1958, Mr. W. L. Klawe, of the Inter-American Tropical Tuna Commission visited Clipperton for a few hours and collected some plants. Finally in August and September 1958, the group of naturalists from Scripps Institution of Oceanography camped on the island and made observations as complete as possible on the flora, fauna, weather and otheraspects. The group included four biologists using skin-diving equipment to study the marine fauna, three icthyologists, two entomologists, an ornithologist, two radio operators, and myself as botanist. The marine biologists working on the reef and in the surrounding ocean, collected marine animals and algae and made ecological observations and I concentrated my efforts on the land flora and terrestrial and lagoon habitats. However, to give a complete view of the atoll, I shall include brief descriptions of certain marine aspects from my limited observations completed from information communicated to me by my companions and extracted from the literature. A list of the recorded land flora and fauna, the latter largely compiled from the literature, will also be included, in-so-far as necessary to give an account of the land ecology. Extensive accounts of the zoology are being prepared by the zoologists of the expedition, and other specialists.

WEATHER AND CLIMATE

The weather and climate of Clipperton Island are very poorly known. The only weather records, outside of brief mentions by visitors, were collected from January to October 1945 when a U. S. Navy station operated on the island, and during August and September 1958 when Messrs. Limbaugh and Chess of the Scripps group made daily observations. The Navy records have never been used and are not available; the others will be utilized below (and see table 1).

The U. S. Hydrographic Office publishes climate and weather data for ocean areas from information transmitted by ships. However the ocean area where Clipperton Island lies is not included: The Weather summary for Central America (H.O. 531, U. S. Hydrographic Office 1948) has no information for areas west of 100° W long. so the 5-degree square for Clipperton is not discussed. Summaries of Pacific Ocean weather often do not extend far enough to the east to include the region of Clipperton. One reason for this state of affairs is probably the small amount of information available in an area where there are no recording stations and few ships records. According to the World Meteorological Organization (Anon. 1957) this is one of the poorly known ocean areas of the world, from which more reports are much needed.

Information on Clipperton must be gained from general sources such as the Weather Bureau's Atlas of climatic charts of the ocean (McDonald 1938) and the U. S. Navy Atlas (1956).

The climate of Clipperton Island is an oceanic tropical one, with little variation in temperature but with seasonal rainfall and storms. The seasonal variation is correlated with tropical cyclone activity which reaches a maximum in the eastern North Pacific in August, September and October. In these months the island frequently experiences winds from a southwest quarter, probably generated by tropical cyclones to the north.

Temperature

According to the most recent compilation (U. S. Navy 1956) the mean monthly air temperature is never below 80°F (26.7°C) and only in June is it equal to or above 82°F (27.8°C). From the same source, the mean air-sea temperature difference for 3-month periods is of the order of -1°F or at most -1° to -3° (air cooler than sea).

In the period August - September 1958, the lowest recorded air temperature was 75°F (23.9°C) at 1300 PDT (Pacific Daylight Time, which is the correct time for Clipperton Island) taken during or just after a rain storm. The highest recorded temperature was 87°F (30.6°C) also at 1300. On sunny days it was quite hot in the sun, but never unbearably so. Night temperatures were not recorded but seemed only slightly below day time temperatures.

Atmospheric pressure

Because Clipperton lies close to the equator and its belt of low pressures, the atmospheric pressure there is always low, with little yearly variation and with probably regular and slight daily variation in calm undisturbed weather. At Colon, Panama (U. S. Hydrographic Office 1948) the yearly variation of mean monthly pressure is only of 2 mb, the highest mean in February (1011.18 mb) and the lowest in June (1009.14 mb). In the same area of Panama, the total daily range at Cristobal averages 2.9 mb for the year, being about 3 mb for October to March and 2 mb for June to August. The highest pressures there occur at 1000 and 2200 local time and the lowest at about 0400 and 1600. From a large sampling of ships' reports, the maxima over the ocean at 10° lat. occur at the same times, and the diurnal range is 2.8 mb. From the short record available (August - September 1958) the daily variation at Clipperton seems to fit this pattern, with a usual daily range of the order of 2 mb. During the period of record, the total range of recorded pressures was 8 mb (1002 to 1010). The low values coincided with bad weather and probable cyclone activity in the area. Since the records are only for August and September nothing can be said of any yearly pattern of atmospheric pressure variations.

Winds

Surface winds at Clipperton Island vary greatly during the year. In the winter the dominant winds are the northeast trades, although they are far from exhibiting the type of constancy experienced on islands farther west. In the summer the winds change considerably and from August to October they blow principally from the SW quarter. During that time, as tropical cyclones dominate in the area, winds are extremely variable and their direction can change rapidly during the day. Table 2 is from MacDonald's atlas. Wind roses for the 5-degree squares are included in the Hydrographic Office's Pilot charts of the North Pacific Ocean and those for the square of Clipperton are reproduced from recent monthly charts in table 4.

Nothing more is known of the wind regime for the island beyond this generalized information except for the August - September 1958 data and the observations of Taylor in September - October 1944 (P. G. Taylor, 1948). In 1958, the recorded observations of wind direction (see table 1) indicate a predominance of winds from the southwest quarter, especially SSW to SW in August and SW to SWS in September. These observations fit well with the generalized data of McDonald's atlas (see table 2). Recorded speeds were up to 26 knots, but the majority of observations in August indicated speeds of 10 knots or less and in September a majority of observations below 20 knots. In August, at least, the strongest winds were not recorded. There is only one record of calm and indeed the almost constant wind, whatever its direction, made living on the island very comfortable.

Rains almost always came from the southwest; from the northeast land strip one could see the dark rain clouds engulf the coconut grove

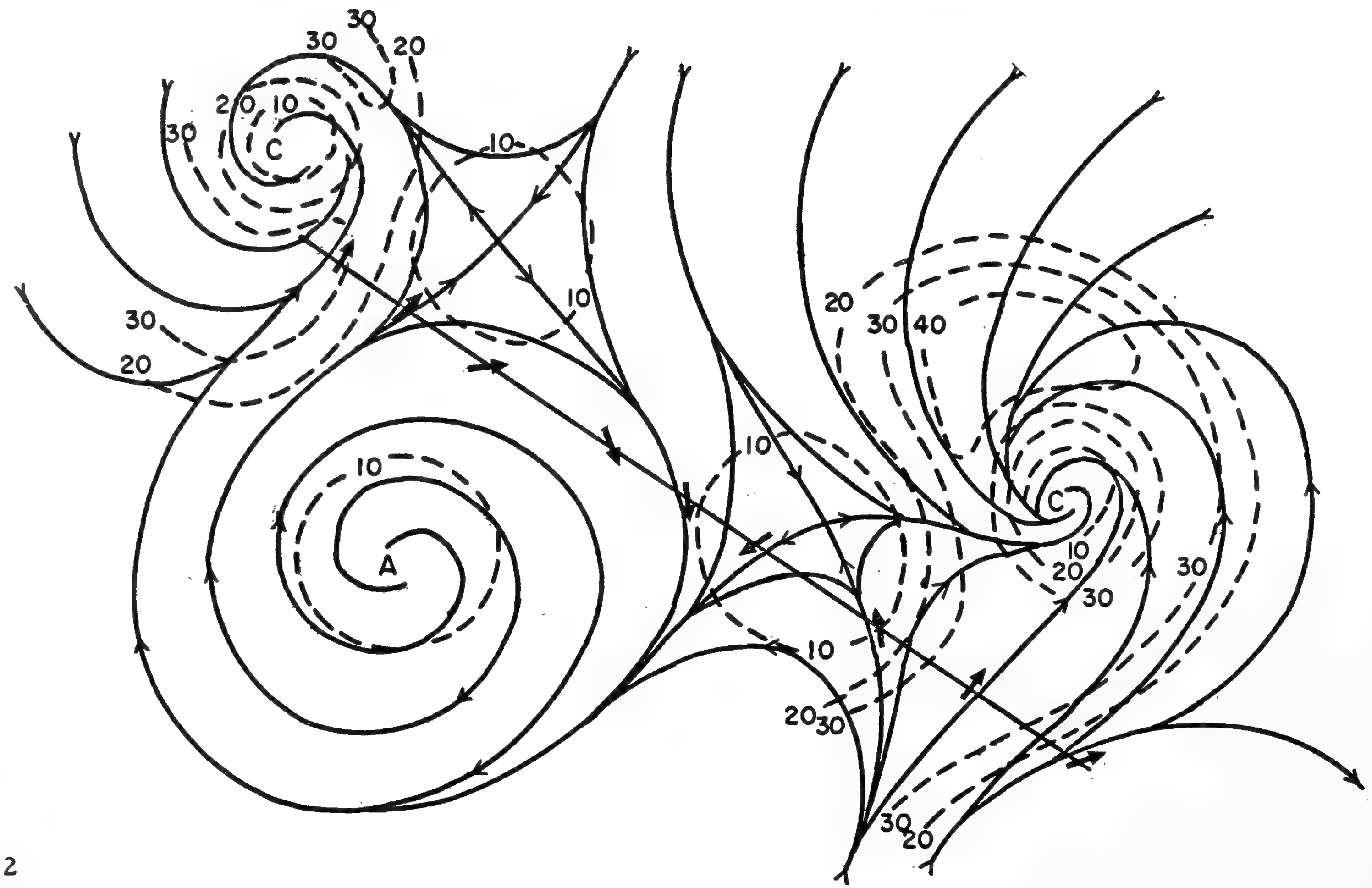


Fig. 2

Reconstructed streamline/isotach chart sequence fitting Taylor's (1948) observations at Clipperton Island. The solid-line curves represent the direction of wind-flow. The isotachs (broken lines) are labelled in knots. The systems (C cyclone, A anticyclone) move generally toward NW or WNW and the successive positions of the island relative to them lie along the straight line. The arrows on this line are observed winds at the island. This line is approximately 1500 miles (2400 km) long. The sequence begins at the top of the line and ends one week later at the bottom. Chart prepared by Professor Ramage.

on the opposite side of the atoll, which promptly disappeared from view, cross the lagoon and eventually reach the northeast side, drenching it with a downpour of incredible suddenness and violence.

In October 1956 (Limbaugh, personal communication) the winds were generally from the southwest, with velocities up to 13 knots.

During his first short stay on Clipperton (from September 9th, 1944) Taylor seems to have encountered reasonably good weather, sunny and clear much of the time, and he gives little information on it in his book (1948). During the second visit (September 21 - October 14) the weather was much worse, culminating in a hurricane (see p. 19). Strong winds from the southwest were common, with squalls up to 35 or 45 knots (estimated) and frequent and rapid changes of surface wind directions were noted.

After spending some time on the island, Taylor summarized the general pattern of winds and weather as follows (p. 194):

"From observations from the time we had been at the island, it seemed that there was a fairly regular weather cycle, with sometimes one period of the cycle more prominent than others.

"We had arrived the second time in the bad sector, when the wind was in the south-west and at a time when this phase was exaggerated, with stormy conditions.

"As the wind swung into north-west the weather had improved, and by the time it had come round to north the sky was clean with scattered cumulus, and the surface wind was seldom more than fifteen knots. Fine weather with light winds and little cloud then prevailed for several days as the breeze worked round east to south and back for south-west, when a high overcast would come over and the underlying cumulus would build up to cumulo nimbus with lightning and storms and the air was uneasy and wild till the wind shifted again toward north. The weather went round this cycle in about a week, and always there was rain from the south-west or west, and sometimes a shower from a local build-up of cumulus in the fine periods."

This sequence fits well the storm tracks commonly observed in the Clipperton region, and has been represented in a streamline/isotach reconstruction (fig. 2) prepared by Professor Ramage (personal communication 1960): "The cycle starts with a tropical cyclone (C), moving NW or WNW to the north of the station [Clipperton]. Winds veer to W and NW and the weather improves as the eastern portion of a small high pressure cell (A) follows the storm circulation across the station. Winds decrease further but weather stays fair as the divergent portion of a col preceding the next cyclone moves over. The cycle is complete when strongly convergent SW winds associated with the next cyclone set in." This reconstruction also compares well with the sequences recognized from the 1958 data (p. 16).

Tropical storms and hurricanes

While not as numerous and destructive as they are in the Caribbean area or the China Sea, tropical storms and hurricanes are common in the southeast North Pacific, with an average of at least 6 storms every year, two of which reach hurricane strength. Hurd (1929 p. 45, 1948) assembles the cyclonic storms of this region into 4 classes: 1. The coastwise storms, that run parallel to the Central American and Mexican coast, 2. those that strike perpendicularly upon the Mexican coast, 3. cyclones of the Revillagigedo Islands and 4. cyclones west of the 125th meridian. The last need not concern us here. The storms of the first class originate somewhere along the American coast, often in the Gulf of Tehuantepec or south of it, or sometimes perhaps as far south as the Gulf of Darien (Ives 1952). They travel usually northwestward in a course parallel to the coast; some swing inland over the Mexican west coast, some travel far into the Gulf of California; a few cross over to the Caribbean area, and conversely, some storms originating in the Caribbean travel to the Pacific side. The storms of this class are far to the east of Clipperton and probably never affect it.

The storms of the 2nd class occur farther west and travel in a northward direction. Those of class 3 travel in a west-north-west direction and are mostly observed north of 15°N. Some of the storms of these 2 classes may form near Clipperton, or pass by it. There are also storms in this area which do not readily fit in the 4 classes, such as some which travel in a westerly course or sometimes even somewhat south of west.

The occurrence of tropical storms in the southeast North Pacific is seasonal, and the monthly distribution is given by Visher (1925) as follows:

Dec. to Feb.	1% each
March to May	0
June	5%
July	11%
Aug.	15%
Sept.	34%
Oct.	24%
Nov.	5%

Because Clipperton is removed from shipping lanes and has only been inhabited occasionally and for short periods of time, historical records of storms and hurricanes are poor. However, some of the storms which are reported west of 110°W and travelling in a northwest direction may have originated near the island or passed it, either as storms or, rarely, as full-size hurricanes. A tropical storm, it must be remembered, need not score a direct hit, or even have reached its full development, to affect an atoll lying only a few meters above sea level. Even storms travelling several hundred kilometers away may generate storm waves high enough to batter the island and even to flood the lower areas of the land strip.

The older records of storms in the southeastern North Pacific are listed by Redfield (1856), the Deutsche Seewarte (1895), Visher (1922, 1925) and Hurd (1929, 1948). In recent years, tracks of storms have been plotted by the Weather Bureau in the National Summary of Climatological Data and the Mariners Weather Log, and by the Hydrographic Office on the Pilot Charts.

From these records the list on the following pages has been extracted. Some of the storms may have passed Clipperton Island close enough to affect it, or may have formed near it. Those marked with a * were reported very near the island, or experienced at it.

Date	Place reported		Source	Ship reporting, and notes
1849, June 21-22	15°55'N	116°16'W	Redfield	Sylph
1850, Aug. 5	14°20'	117°	"	Como; winds N, W, S
1850, Oct. 3-4	13°30'	116°50'	"	Amazon: winds SW, SE, E, N, W and SW again
1852, July 16-19	15°	115°	"	Panama, and Empire
1852, July	13°	112°	D. Seewarte	(same storm as above?)
1855, Aug. 8-9	15°	116°31'	Redfield	Gertrude Maria; winds NE, NNW, WNW, W, SW
*1857, June 20	11°	110°	D. Seewarte	Seamans Bride; storm in formation
1858, Aug. 17	13°	115°	"	Gellert; winds E, N, W, S
*1865, July 25	10°	109°	"	Zanzibar
1871, July 3	16°	117°	"	Shelehoff
1882, July 31	13°	118°	"	Dora, and Adelaide
1891, Aug. 7	11°	107°	"	Dorothea
*1895, Sept. 29-Oct. 1	9°	112°	Hurd 1929	"Strong southwesterly squalls were experienced by a vessel at anchor there [Clipperton] on the 29th."
1899, Aug. 27-31	14°	112°	Hurd 1929	
*1910, Sept. 8-11	10°37'	109°46'	Hurd 1948	
1913, Aug. 23	17°49'	121°22'	Visher 1925	Robert Searles

Date	Place reported		Source	Ship reporting, and notes
*1915, June?	Clipperton		Morris 1934	Storm destroyed Mexican camp
1915, Sept. 4-5	15°40'	109°40'	Kimball 1915	Calliope
1922, July 31	14°N	118°W	Visher 1925	
1922, Sept. 9-10	16°12'	113°44'	Visher 1925 and Hurd 1948	Bessemer City A very intense and very large hurricane
1922, Oct. 13-16	15°	110°	Hurd 1948	
1928, Oct. 15-16	16°34'	113°29'	"	
1936, Oct. 27-29	12°	106°	"	
1940, Sept. 22-24	14°	110°	"	
1940, Oct. 6-11	12°	110°	"	
*1944, Oct. 12	Clipperton		Taylor 1948	See below, p.
1955, June 5-8	14.5°	111.1°	N'al Summary	Hawaiian Citizen; moving N
1955, June 7-10	11.4°	107.4°	"	Hawaiian Fisherman; center charted at 11.5°, 109.7°, moving NW
1956, May 17-19	14°	111°	"	Arapahoe; center estimated at 13.7°, 111.6°, moving W
*1957, July 14-26	10.3°	109.5°	" and Mar. Weather Log, March 1958	Gravel Park; moving W then WNW

Date	Place reported	Sources	Ship reporting, and notes
*1957-1958	Clipperton		Vegetation destroyed and gravel sheet laid over northeast side of I. See pp. 70-72 . No storm on record (Mar. Weather Log, 1958) seems tocorrespond to that which must have hit the island between Nov. 1957 and May 1958. It is rather disappointing that this storm cannot be identified. It may have been a relatively minor or local disturbance, of course, and may have occurred at a time when currents and tides were such that they intensified the effect of its storm waves.
*1958	Clipperton		During the survey of the island in Aug.-Sept., there was some bad weather, including a storm in the middle of September. On Sept. 17, its effects could be observed on the southwest side of the island (Limbaugh, unpublished data): the shore had been cut, much gravel removed and redeposited at the northwest corner, and beach-rock exposed that had previously been covered by sand. The data collected in Aug.-Sept. (see table 1) also help backtrack storms observed later elsewhere. The following sequences were reconstructed by Professor Ramage (personal communication):
"(a) Aug. 8			"A depression or tropical storm moved toward WNW, the center passing just north of the station. [Clipperton]. Almost certainly this is the storm which was first located when the ship HAWAIIAN TOURIST reported NE 45 knots at 17.8 N, 120.8 W at 1800 GMT on the 12th.

Date	Place reported		Sources	Ship reporting, and notes
*1958 (b) Aug. 11	Clipperton			"A small depression or tropical storm moved on a westerly course just north of the station.
(c) Aug. 17-25				"The center of a small tropical storm passed across the station from SE to NW then possibly intensified not far to the NW.
(d) Aug. 27 - Sept. 3				"A depression appeared to develop and slowly intensify in the Clipperton area finally moving to the N of the station on the 3rd. It continued to move N and then NW being first located when winds on the island of Roca Partida (19N, 112W) increased to SE 40 knots at 1200 GMT on the 6th. By this time, or shortly thereafter winds of over 100 knots had developed near the storm center." [The storms mentioned are recorded in Mariners Weather Log for March 1959.]
1959	Clipperton			None of the storms reported for 1959 in Mariners Weather Log, March 1960, seems likely to have affected Clipperton Island.
1960	Clipperton			None of the storms reported for 1960 in Mariners Weather Log, March 1961, seems likely to have affected Clipperton Island.
1961, July 10	16°N	113°W	Mar. Weather Log, Sept. 1961	Tropical storm Joanne moving westward; on the 11th, winds near center 60 knots.
July 14	17°	107°	"	Hurricane Kathleen moving northwestward; maximum winds 70 knots.

Date	Place reported		Sources	Ship reporting, and notes
1961, July 15	19°	109°	Mar. Weather Log, Sept. 1961	Kathleen
July 16	16°	112°	"	Kathleen moving west, 60 knot winds near the center.
July 14	14°	97°	"	Hurricane Liza, winds near the center 70 knots.
	to			
July 15-18	20°	118°	"	Liza moving west-northwestward, maximum winds near 50-60 knots.
July 20	15°	109°	"	Tropical storm Madeline (see p. 23), moving westward, winds near center 55 knots.
1961, Aug. 4-5	18°	115-120°	Mar. Weather Log	Tropical storm Naomi, winds 30-50 knots.
1961, Sept. 6-8	17°	110°	"	Tropical storm Orla moving northwestward, winds 60 knots.
	to 22°	114°		

The following is condensed from Taylor's book (1948, pp. 224-254), the only eye-witness account of a Clipperton Island hurricane. October 12, 1944. Soon after dawn, fresh breeze from the north, sky dark, heavily overcast, nimbus hiding the tops of cumulus, and fast moving clouds below. Altimeter of aircraft set at zero read 29.95 (1010.8 mb), low on the scale of earlier daily readings, but no lower than had already been recorded. At breakfast time, the fresh puffs on the lagoon had changed to squalls, the wind swinging around as its force increased soon reaching 50 knots. Rain came in blinding sheets, drenching the camp. The squall passed, but the wind hardened into a steady blow, and within an hour of coming ashore for breakfast, little remained of the camp. (This camp was on the west lagoon shore, just north of North Pincer). Suddenly the wind eased to 30 knots, but soon after swung into east and became worse. Half an hour later there was another slight easing of the wind, but soon it swung more towards south and became more violent. "About two hours after the first squalls the wind swung nearer to south... The Rock was blotted out and the lagoon was sweeping towards us in a wall of water like spray from many hoses, reaching from shore to shore and leaving no definition between sky and lagoon. It was a fantastic sight..." The wind was still blowing with hurricane force, estimated as between 80 and 100 knots. A little before noon it swung to south and the lagoon waves abated somewhat, but danger from the ocean became greater. In the coconut grove: "the heads of the palms were streaming back in windblown fronds like the hair of a girl in the wind. The taller palms were bent like tight-strung bows, and held till it seemed that their spines must break. Their fronds were awash in the blast of air... And now, instead of the horizon dark with cloud against the flat rim of the land, there was a cold white stream of breaking surf, visible above the land, and roaring madly at the island... Already only the reef was stopping the rollers, which ... were higher than the land." If the hurricane were to swing into southwest the ocean would flood the strip of land where the camp was. Trying to reach the coconut grove only 200 yards away, two men went first oceanward to seek some shelter on the ocean side of the beach ridge, but the sea was already far up the beach, and kept rising. "It was roaring by now not two feet below the top of the bank. The surge was sending little rivers trickling through the stones over the top... Now there were no rollers breaking on the reef. The whole ocean was tearing by in a roaring flood of water, clawing at the island." The pigs and some birds had taken shelter in the coconut grove.

About 3 p.m., there was a definite lightening in the sky and a slight easing of the wind, which definitely slacked up a few minutes later. Back in the aircraft, the altimeter showed steadily rising pressure. By 5 p.m., the wind had dropped to a hard blow of about 40 knots, and by night, eased to about 30 knots. The next day was sunny, with some showers and a light breeze from the south.

Two Catalina flying-boats were anchored in the lagoon during the storm and barely survived it. On the 14th, with fine weather and a light southerly wind, Captain Taylor took off in his flying-boat the Frigate Bird for the Marquesas and Bora Bora.

Rainfall

The Pacific coast of Central America and the ocean area between it and Clipperton Island have a decidedly seasonal pattern of rainfall, with the months from December or January to April or May drier than the summer and fall. This pattern apparently is still valid westward as far as Clipperton Island. The Sailing Directions (U. S. Hydrographic Office, 1951) indicate that there is a "dry" season in December to May, but just how dry is not known. This information is probably based, in part at least, on observations furnished by the guano workers who lived on the island during the last years of the 19th and the first years of the 20th centuries, as it was already included in the 1902 edition of the Sailing Directions. For instance, P. J. Hennig kept notes on the weather during his stay as "keeper" of Clipperton and is said to have forwarded them to the Hydrographic Office with his map (cf. p. 6). I could not find a record of his data, but a newspaper account (Anon. 1897) quotes excerpts from them:

"Mr. Hennig, who is a man of ability as well as patriotism, kept an accurate log of the island from October 1, 1896 to August 5, 1897. He has presented the log to the hydrographic office, and it is the first valuable record of the Clipperton conditions.

"October had almost daily rains, with southerly and southwesterly winds. There was about as much rain in November, several heavy thunder storms and a few hard squalls. December was sultry, with many rainy days. Little rain fell in January, and the weather was hot. The word 'pleasant' occurs frequently in the February records. Severe thunder storms were again noted in March, April and May. The record of the Kinkora disaster is as follows:

"Friday, April 30th--Wind N. N. S. Moderate breeze with squalls in first part; then gentle breeze with squalls and light rain, but mostly fair, hot, sultry weather. Heavy surf. At 8 a.m., stranger in W. S. W. in sight.

"Saturday, May 1st--Wind N. E. by E. Moderate weather; heavy surf. Stranger coming around east side of island, flying British colors. Proved to be ship Kinkora, Belfast, water-logged, and bad steering. Beached at 5 o'clock. All hands saved.

"Easterly and northerly winds prevailed from the beginning of November until June; then the south and southwest winds returned.

"June and July were hot months, with occasional rains and squalls."

In addition, the manuscript diary of John Arundel for July and August 1897 (which I have seen by courtesy of Mr. H. E. Maude, and which is quoted here with the permission of Mrs. Sydney Aris) includes this observation of one of the workmen, who "says it rains nearly every day - showers - though you may have 2 or 3 days without - but the winter months are as a rule the driest - though he has never known a month without rain ... In the winter dry season - 3 or 4 mos. you have North East trades."

The only recent observation bearing on this "dry" season is the fact that the vegetation on Clipperton Island in August 1958, appeared to be recovering from a dry spell: many plants had dead twigs together with young new growth. In May 1958 (Klawe, personal communication) the dry condition of the plants was striking. Perhaps even more significant are the thick "trunks" (see p. 78 and Sachet 1962) of the beach morning-glory (Ipomoea pes-caprae) which suggest dying back of the vines during an unfavorable season. However, it must be kept in mind that with a very porous substratum such as is found on coral islands generally, effective drought may occur even with a rather high total precipitation if the latter is irregular. Certainly the dry season at Clipperton cannot compare with the intense droughts occurring on some desert atolls of the central equatorial Pacific where occasionally there is no rain at all for months. The drier season is indicated in the world atlases (McDonald, U.S. Navy) by a smaller number of observations reporting rainfall (table 3). While there are still many observations reporting rain during the winter and spring, they may correspond to light showers very different from the downpours of the summer months.

The maps in the same atlases, however, indicate that an area of very abundant rainfall lies to the west of Clipperton Island. In the Navy atlas, the January isogram for 40% of observations reporting rain forms a sort of ellipse to the southwest of Clipperton, between latitudes 5° and 9°N and longitudes 114° and 127°W. The size and position of this ellipse vary somewhat during the year and while it is formed by the 40% isogram from November to February, it is enclosed by the 30% or 35% isograms for the rest of the year. What the frequencies of observations reporting rain represent in terms of height of rainfall is not mentioned. However, Möller (1951) published quarterly maps of rainfall based in part on the frequency of rainfall figures of McDonald's atlas, which are comparable to those of the Navy atlas, but based on fewer observations and compiled only from Greenwich noon observations (5 a.m. Clipperton time).

Corresponding to the wet region of the Navy atlas, Möller shows for the quarter December - February the isohyet for 400 mm forming a wide strip in the space 0° to 10°N and stretching east to about 97°W. Clipperton Island is halfway between the 400 and 200 mm lines. In the March to May quarter, Clipperton is still between those lines, and the 400 mm tongue scarcely reaches east of 100°W, but is wider than before. On the June - August map it extends eastward all the way to the Atlantic side of Central America, and Clipperton Island is in the middle of it. During that quarter, according to the map, the Gulf of Panama has over 600 mm of rain and the area of the isthmus over 1000 mm. In the last quarter, the 400 mm isohyet still extends to the Atlantic side of Central America, but it crosses the meridian of Clipperton only a short distance north of the island which presumably receives something over 400 mm of rain in that quarter.

Such calculated figures cannot give an idea of the exact pattern or amount of rainfall, but are useful as indications of general trends. Clipperton Island is situated between an area of year-round high rainfall to the southwest and one of marked seasonal rainfall to the east, and retains in attenuated form the seasonal pattern of the latter, with lower

rainfall in the winter and spring. The rains during that period "probably result from persistent low-level wind convergence but in the summer... cyclonic depressions or storms seem to be the cause" (Ramage, personal communication).

In August and September 1958, exact measurements of all rainfall could not be taken, but an ordinary tin can was kept in the open during the heavy rainstorms which occurred with southwesterly squalls. As much as 125 and 150 mm of rain were recorded during 24 hour periods of violent rain. The total amount recorded for the period August 11 - September 17 was 890 mm.

No one who is not familiar with the wet tropics can imagine this type of rain. There is warning from the approaching dark cloud, but when the rain starts, it is with its full intensity and in two seconds one is completely drenched. Protecting notebooks and films is a haunting worry. Because of the strong winds which bring the rain squalls, there is much of what we called "horizontal rain" which seems wetter and more able to get into shelters than the usual kind. Some such downpours last for hours.

In October 1956 (Limbaugh, personal communication) it rained almost every afternoon or evening. The amount of rain was quite variable, probably never exceeding an inch (25 mm) in any one day.

The measurements made by Limbaugh in 1958, his observations in 1956 and those of Taylor's indicate that much more rain falls in the Clipperton area than Möller deduces (about 300 + 350 + 600 + 450 = 1700 mm). Professor Ramage therefore has suggested another hypothetical calculation which may give a better idea of possible rainfall distribution on Clipperton.

"Palmyra Island, also a coral speck is located at $5^{\circ}53'$ N, $162^{\circ}05'$ W in the western part of the heavy rainfall region which also affects Clipperton. Between 3 and 5 years' rainfall measurements at Palmyra give an annual mean of 4445 mm with little apparent seasonal variations in rainfall intensities. We might assume that average rainfall intensities are about the same for Clipperton and that the mean rainfall in both areas is proportional to the average number of observations of rain recorded in the Navy atlas. The atlas shows that over the year 19.7% of observations in the Palmyra area and 22.2% of observations in the Clipperton area recorded rain. We might then estimate the annual rainfall at Clipperton as

$$\frac{4445 \times 22.2}{19.7} = 5020 \text{ mm}$$

and then by prorating among the months in accordance with their rain observation frequencies, come up with this hypothetical distribution:

J	F	M	A	M	J	J	A	S	O	N	D"
347	192	211	186	404	539	501	484	427	631	559	539

It must be pointed out that the difference in the vegetation of Palmyra and Clipperton is much more striking than would be expected from these figures, and that even the somewhat greater seasonality indicated

for Clipperton would scarcely account for it. Although an absolute correlation between vegetation and rainfall is not expected where such small floras are involved, and considering that tree species may never have reached Clipperton, still this discrepancy suggests that caution should be observed in accepting these hypothetical figures.

A new source of information has recently become available in the photographs taken by the weather satellite Tiros III. The following paragraphs describing this type of information were contributed by Mr. Lester F. Hubert, Meteorological Satellite Laboratory, U. S. Weather Bureau.

"Meteorological observations made on Clipperton Island have been inadequate to provide a reliable climatology. A small sample of observations is especially vulnerable at this location because several years in succession may display a single type of meteorological regime, followed by a year of radically different weather. This is due to the fact that Clipperton Island is situated on the boundary of the Pacific dry zone--a tongue of desert-like weather lying just north of the Equator. Approximately each decade, during the El Niño* years, this zone is disturbed, that is, becomes more rainy and shifts its position.

"The meteorological satellite now provides a means of obtaining the information necessary to reveal the rainfall regime, and the exceptional cases that are sometimes more important than the "average." TIROS pictures have demonstrated the potential of detecting and tracking cyclonic disturbances near Clipperton. They show that many more cyclonic storms occur in the area than were previously known from inadequate conventional weather observations. The picture obtained by TIROS III on July 22, 1961, from an altitude of approximately 450 miles, shows the curvature of the earth, the approximate location of Clipperton Island, and that of hurricane Madeline, with bright curved cloud bands that are believed to produce precipitation. Infrared measurements from the satellite can be used to approximate cloud heights, thereby distinguishing between the thick shower-producing clouds reaching up to 15-18000 ft. and higher, even up to the tropopause, and the shallow clouds reaching to 4-5000 ft that usually yield no significant precipitation. During the anomalous (El Niño*) years, we may find that disturbances (cyclonic storms) pass over Clipperton Island. We are now in a position to commence accumulating data for this neglected part of the ocean."

The photograph of Madeline represents a typical summer cyclone situation in that part of the world. The orientation of the cloud bands seems to indicate that the winds at Clipperton were probably from the southwest (cf. pp. 10-11).

* El Niño is a warm tropical current from the north, that flows along the north coast of South America (Ecuador, northern Peru) down to about 6°S, during the southern summer. Some years, at more or less regular intervals, it reaches farther south, pushing away from the coast the cold waters that usually flow along it. At the same time, important atmospheric disturbances take place, especially unusually abundant rains that may affect vast regions.

Atmospheric humidity

As could be expected in a wet tropical climate, atmospheric humidity is very high. The lowest relative humidity recorded in August - September 1958, as calculated from the depression of the wet bulb was 69%.

Cloudiness and visibility

The U. S. Navy Atlas presents data on cloudiness over the oceans on monthly charts including two series of isograms, one representing "% frequency of low cloud amounts 6/10 or more," i.e. cloudy, the other representing "% frequency of total cloud amount 2/10 or less," i.e. relatively clear. Extraction of positions of Clipperton Island in relation to these lines gives, for low clouds, monthly figures ranging from between 20 and 30% in November, in the neighborhood of 30% for most months, and approaching or exceeding 40% in July, September and October.

The same extraction of positions for total cloudiness gives figures less than 20% for the months from May through December, and ranging between 20 and 30% for the remainder. Thus both sets of isograms indicate a high degree of cloudiness throughout the year, with the summer months, from April to October, even more cloudy than the winter.

On the basis of 85 observations between August 9 and September 16, 1958, the sky was completely cloud-covered over 3/4 of the time and half or less covered less than 1/5 of the time. The clouds were generally cumulus or cumulonimbus, occasionally stratus or altostratus, with cirrus usually vicible when there were breaks in the lower cloud layers. The bases of the principal clouds were usually estimated at between 600 and 2000 m altitude.

Visiblity is generally always good at Clipperton Island except during rain storms.

Day of the Month (Aug. 1958)	8	9				10			11	
Time (PDT)	2100	0900	1300	1700	2100	0900	1700	2100	0900	1700
Wind direction* from	315-324 NW	275-284 WNW	215-224 SW	215-224 SSW	195-204 SSW	195-204 SSW	195-204 SSW	215-224 SW	215-224 SSW	90? E?
Wind speed Knots	10	6	8	8	10	13	14	14	9	8
Atmospheric pressure mb: 1010										
1009								x		
1008						x			x	
1007										
1006	x	x			x		x			x
1005			x							
1004										
1003				x						

*Direction from which wind is blowing, in degrees, clockwise from 0° = North

Day of the Month (Aug. 1958)	12		13		14		15	
Time (PDT)	0900	1700	0900	1700	0900	1700	0900	2100
Wind direction from	205-214 SSW	215-224 SW	205-214 SSW	175-204 S	195-204 SSW	205-214 SSW	195-204 SSW	5-14? N?
Wind speed Knots	10	13	18	12	18	11	3	8
Atmospheric pressure mb: 1010								
1009								
1008	x		x		x			
1007							x	x
1006		x		x		x		
1005								
1004								
1003								

Table 1. Winds and atmospheric pressure at Clipperton Island, 1958, from data collected by C. Limbaugh and T. Chess

Day of the Month (Aug. 1958)	16				17	18	19	20		21	22
Time (PDT)	0900	1300	1700	2100	0900	2100	0900	0900	2100	0900	0900
Wind direction from	35-44?	45-54	55-64?	115-124	225-234	245-254	275-284	205-214	245-254	85-94	235-244
	NNE?	NE?	ENE?	ESE	SW	WSW	WNW	SSW	WSW	E	WSW
Wind speed Knots	5	5	8	1	10	10	8	5	5	9	5
Atmospheric pressure mb: 1010											
1009											
1008	x									x	x
1007		x		x	x			x			
1006			x				x		x		
1005											
1004						x					
1003											

Day of the Month (Aug. 1958)	23		25	26	27	28	29	30	31
Time (PDT)	0900	2100	0900	2100	0700	0700	1000	0800	1100
Wind direction from	185-194	235-244	215-224	145-154	225-234	205-214	155-164	235-244	45-54
	SSW	WSW	SW	SSE	SW	SSW	SSE	WSW	NE
Wind speed Knots	8	12	3	5	4	20	5	10	4
Atmospheric pressure mb: 1010									
1009									
1008	x		x						
1007		x		x			x		x
1006					x	x		x	
1005									
1004									
1003									

Table 1, p. 2

Day of the Month (Sept. 1958)	1	2			3		
Time (PDT)	0700	0500	0700	1700	0600	0800	0900
Wind direction from	145-154 SSE	105-114 ESE	215-224 SW	225-234 SW	215-224 SW	235-244 WSW	255-264 WSW
Wind speed Knots	4	1	4	10	21	22	26
Atmospheric pressure mb: 1010							
1009							
1008							
1007							
1006							x
1005	x					x	
1004			x		x		
1003		x		x			

Day of the Month (Sept. 1958)	4						5		6		
Time (PDT)	0600	0700	0800	1000	1100	2300	0700	1800	0700	1000	2200
Wind direction from	215-224 SW	205-214 SSW	205-214 SSW	205-214 SSW	215-224 SW	225-234 SW	205-214 SSW	225-234 SW	215-224 SW	215-224 SSW	205-214 SSW
Wind speed Knots	24	20	19	20	18	16	19	23	18	18	16
Atmospheric pressure mb: 1010											
1009											
1008											
1007											
1006				x	x					x	
1005		x	x			x	x				x
1004	x							x	x		
1003											

Table 1, p. 3

Day of the Month (Sept. 1958)	7		8	9	10	11	
Time (PDT)	0700	2200	0700	0600	0700	0500	0700
Wind direction from	215-224 SW	235-244 WSW	245-254 WSW	245-254 WSW	345-354 NNW	215-224 SW	calm
Wind speed Knots	15	9	9	8	2	02	00
Atmospheric pressure mb: 1010							
1009							
1008					x		x
1007		x	x	x			
1006						x	
1005	x						
1004							
1003							

Day of the Month (Sept. 1958)	12								
Time (PDT)	0700	0800	0900	1100	1300	1600	1900	2000	2100
Wind direction from	235-244 WSW	235-244 WSW	235-244 WSW	245-254 WSW	255-264 WSW	255-264 WSW	245-254 WSW	245-254 WSW	245-254 WSW
Wind speed Knots	06	06	06	06	06	05	07	05	04
Atmospheric pressure mb: 1010				x					
1009		x	x					x	x
1008	x				x		x		
1007									
1006						x			
1005									
1004									
1003									

Table 1, p. 4

Day of the Month (Sept. 1958)	13			14		15			
Time (PDT)	0800	1800	1900	0900	1400	0700	0800	1300	1600
Wind direction from	265-274 W	315-324 NW	315-324 NW	265-274 W	235-244 WSW	225-234 SW	195-204 SSW	235-244 WSW	205-214 SSW
Wind speed Knots	04	22	21	12	14	17	20	02	17
Atmospheric pressure mb: 1010									
1009	x								
1008									
1007									
1006									
1005		x	x	x				x	
1004						x	x		
1003					x				
1002									x

Day of the Month (Sept. 1958)	16		17	
Time (PDT)	0700	1100	0600	1100
Wind direction from	215-224 SW	225-234 SW	225-234 SW	205-214 SSW
Wind speed Knots	24	23	17	19
Atmospheric pressure mb: 1010				
1009				
1008				
1007				
1006				x
1005		x		
1004	x		x	
1003				

Table 1, p. 5

Table 2. Winds in Clipperton Island 5-degree square. Adapted from McDonald 1938 and U. S. Navy 1956

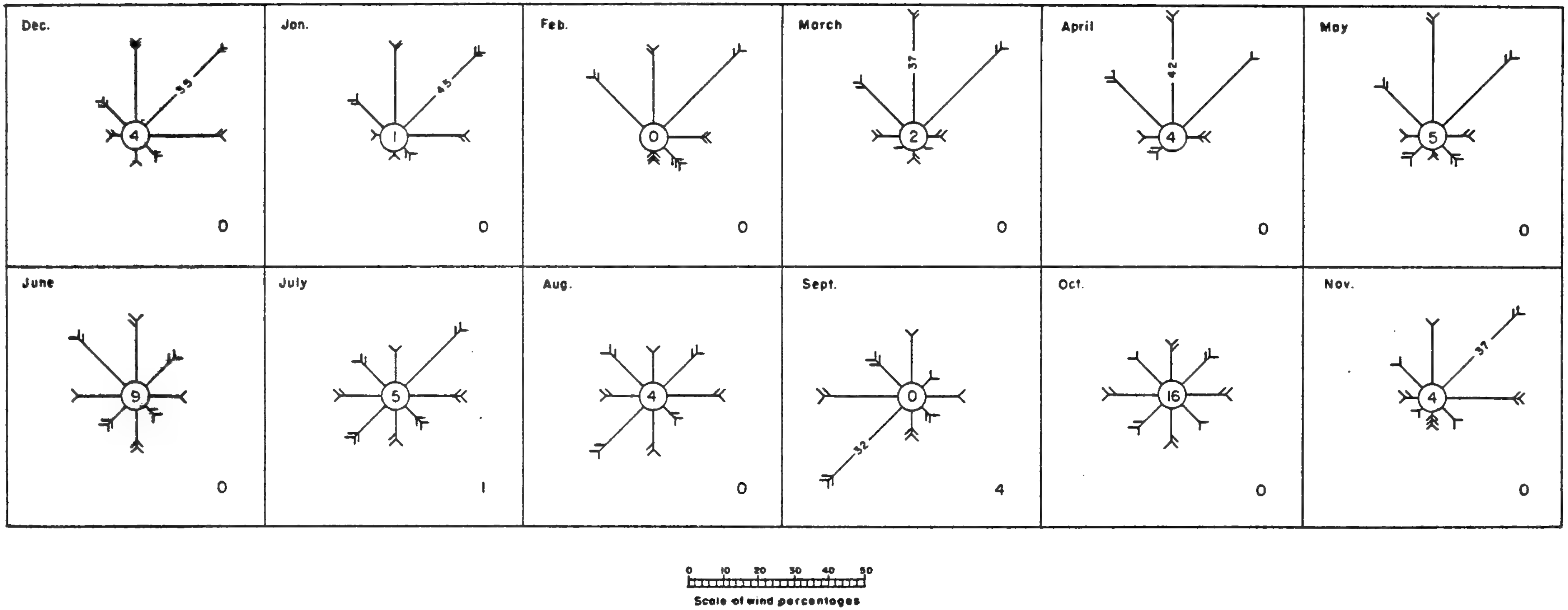
	Wind, dominant dir. from quarter	Dominant constancy: 1 = 25-40% from quarter 2 = 41-60% from quarter 3 = 61-80% from quarter 4 = 81% and over quarter	% frequency wind speed Beaufort 3 or less (10 knots or less) from Navy Atlas	Computed resultant wind from quarter	Resultant wind velocities (Beaufort 1-4).	Average velocity in knots for 3-months period	% observ. indicating dead calm	% observ. indicating gale or stronger (Beaufort 7 and higher)	% observ. indicating fresh gale or stronger (Beaufort 8 and higher)	% observ. reporting haze
Dec.	NE	3	60	NE	1-2			below 1		
Jan.	NE	3	40	NE	2-3	10-12	1	below 1	below 0.5%	below 1
Feb.	NE	2-3	over 70	NE	2-3			1-5		
March	NE	3	60	N	2-3			below 1		
April	NE	3	70-80	N	2-3	8	1-5	1	below 0.5	1-5
May	N	3	over 70	N-NE	1-2			below 1		
June	N	1	70-80	NW	0-1			1-5		
July	NE	1	50	N of E	1	8-10	1-5	1-5	1	1-5
August	SW	2	60	SW	1-2			1-5		
Sept.	SW	1-2	40	WSW	1			5		
Oct.	W	1	50	N of W	0-1	8-10	5-10	1-5	1	below 1
Nov.	NE	3	60-70	NE	1-2			below 1		

Table 3. Rainfall for Clipperton Island 5-degree square, adapted from atlases

<table>
<tr><th>Months</th><th>% observations reporting precipitation (isograms) (Navy Atlas)</th><th>% observations reporting steady rain for 5 degree square (MacDonald Atlas)</th><th>% observations reporting thunderstorms (MacDonald Atlas)</th></tr>
<tr><td>Dec.</td><td>Clipperton between 20 & 25% isograms</td><td rowspan="3">5</td><td rowspan="3">1-5</td></tr>
<tr><td>Jan.</td><td>Clipperton between 20 & 25% isograms</td></tr>
<tr><td>Feb.</td><td>10</td></tr>
<tr><td>March</td><td>5-10</td><td rowspan="3">5</td><td rowspan="3">1-5</td></tr>
<tr><td>April</td><td>5-10</td></tr>
<tr><td>May</td><td>20</td></tr>
<tr><td>June</td><td>25-30</td><td rowspan="3">10-15</td><td rowspan="3">5</td></tr>
<tr><td>July</td><td>above 25</td></tr>
<tr><td>Aug.</td><td>20-25</td></tr>
<tr><td>Sept.</td><td>20-25</td><td rowspan="3">10</td><td rowspan="3">1-5</td></tr>
<tr><td>Oct.</td><td>30-35</td></tr>
<tr><td>Nov.</td><td>25-30</td></tr>
</table>

Table 4. Wind roses for Clipperton Island's 5-degree square (10-15°N, 105-110°W) from Pilot charts

The wind percentages are concentrated upon 16 points of the compass. The arrows fly with the wind. The length of the arrow, measured from the outside of the circle on the wind rose, when compared with the attached scale gives the percent of the total number of observations in which the wind has blown from or near the given direction. In some instances the full length of the arrow cannot be shown. In such cases the arrow is broken and the percentage is shown numerically, between the broken lines. The number of feathers shows the average force of the wind on the Beaufort scale. The numeral in the center of the circle gives the percentage of calms, light airs, and variable winds. The numeral in the lower right corner shows for the month the percentage of ship reports in which gales have been recorded.


Dec.
4
35
0
Jan.
1
45
0
Feb.
0
0
March
2
37
0
April
4
42
0
May
5
0
June
9
0
July
5
1
Aug.
4
0
Sept.
0
32
4
Oct.
16
0
Nov.
4
37
0
0
10
20
30
40
50
Scale of wind percentages

HYDROGRAPHY

Surface currents

Clipperton Island is located in an ocean area of variable surface currents. In the eastern part of the tropical Pacific ocean, the North Equatorial Current flows in a general east-west direction around latitude 10° N. The South Equatorial Current flows in the same general direction, straddling the equator and with a large part of its water moving in the northern hemisphere. The Equatorial Countercurrent, flows from west to east between the other two and always in the northern hemisphere. The exact position of these currents varies seasonally. Information on the currents around Clipperton can only be derived from very general charts and summaries applying to the eastern part of the Pacific and the central American region. Most of the available data of this sort are compiled from ships' reports and published for the use of ships (U. S. Hydrographic Office 1947). They have also been summarized by Schott (1935, maps 29, 30). Very little of such information has been collected near Clipperton Island because it is removed from shipping lanes.

According to Schott, the North Equatorial Current flows westward around Clipperton during the winter months, and according to data in the U. S. Hydrographic Office (Mr. W. E. Malone, personal communication) at speeds from 0.5 to 1.0 knot. At this season the Equatorial Countercurrent is well to the south of the island and, according to some authorities, it is weak and at times nonexistent as a well-defined current.

During the summer months the Countercurrent is better developed and according to Malone (personal communication) the island lies in the shear zone between it and the North Equatorial Current. Schott's map would indicate that the Countercurrent itself always flows past Clipperton in the summer but this generalization is probably only occasionally valid. In the summer of 1958 (Knauss and Pepin 1959) the Countercurrent was 250-300 km wide.

During the IGY there was a great increase in the work on ocean currents and particularly on those of the Eastern Pacific. Indeed the main purpose of the Doldrums Expedition was to study the Equatorial Countercurrent. Most of the data from such recent surveys are not yet available but John Knauss, leader of the Doldrums Expedition, considers (personal communication) that the Countercurrent runs about 50 miles south of Clipperton most of the time and probably does not move as far north as Schott has it, in fact probably does not even move as far north as Clipperton every year. The Countercurrent is irregular, can change its direction or speed, or can even disappear within a very short period (Knauss 1960). Besides the seasonal variation in the surface currents around Clipperton, the situation may be complicated by the occurrence of transverse flow between the North Equatorial Current and the Countercurrent. These variable currents during the summer show a slight predominance of east and northeast sets with speeds of 0.5 knot or less (Malone, personal communication).

With regard to the transport of propagules of plants and animals by surface currents it must be kept in mind of course that when the Countercurrent is well developed, much of its water mass is deflected northwestward

as it reaches central America and flows back toward the west with the North Equatorial Current, therefore it is not impossible that some Indo-Pacific organisms might reach Clipperton Island by this roundabout way rather than by direct eastward flow.

Waves

There are many ways in which ocean waves of various types affect oceanic islands and coral atolls especially. For example, the very growth of the living reef is linked to the amount of surf and consequent varying oxygenation of the surface water; wave erosion and deposition are major factors in the arrangement of materials that form atolls. The reverse influence of an island as an obstruction to swells is also well known theoretically and has been demonstrated for some (Arthur 1951). In a detailed study of an atoll, therefore, a knowledge of ocean wave patterns is necessary, but it has not generally been feasible, so far, to obtain such knowledge. Only for a few atolls has information on waves been available to be correlated with data on the morphology or ecology (Munk and Sargent, 1954, Guilcher, 1956).

In the case of Clipperton, hardly anything is known of the pattern of waves and their influence on the atoll. Yet, besides the more general effects alluded to above, waves have one very practical role on Clipperton, that of entirely preventing landing on the atoll more often than not. The Sailing Directions (U. S. Hydrographic Office 1951) as well as most accounts of visits to the island are replete with warnings of the dangers and difficulties that may be encountered, and make it clear that it is often impractical to attempt a landing: "On the reef, the sea breaks heavily and continually; the surf is terrific and at times covers the whole island" (this last observation is exaggerated, although storm waves can cover the whole width of narrow parts of the atoll ring and pour into the lagoon). There are times, however, when sea and wind are calm and when it is possible to land easily with a small boat over the shallow reef. This was the case when I landed on Clipperton and when I left the island.

Waves approaching the island, because the reef front falls off very rapidly, suddenly find themselves over a very shallow area, and break with great violence, the continuous line of such breakers forming the surf (for a general discussion of this and related phenomena, see Bascom 1959).

Goua (1952) considers that the swells coming from the southwest to southeast 9 months of the year are refracted around the reef and break on the north part of the atoll, while in February, March and April the northeast trade wind prevails and the southern swells diminish, spring therefore being the best time to effect landings. This is also rather over-generalized and simplified.

Except for these remarks, and for some observations made from shore by Limbaugh in 1958 (ined.) the only available information on waves applicable to Clipperton is that generalized from ships' observations in the form of roses for the 5° square (10°-15° N, 105°-110° W) in the U. S. Hydrographic Office Charts of Seas and Swells (1944), and reproduced here

as table 5. Seas may be conveniently defined as reasonably large waves, in the area of their generation, and are characterized by steep sides and sharp crests. Their energy content is generally being augmented by the wind. Waves that have left the area of generation--no new energy being added by the wind--are called swell. They have less steep sides, rounded crests and longer periods than are general for seas. They are gradually losing energy while travelling over great distances, often thousands of kilometers from their area of generation.

In any oceanic area the wave pattern is extremely complex, resulting from seas generated locally and swells arriving simultaneously from several directions and points of origin. The effects on atoll morphology are correspondingly difficult to unravel, but are nevertheless very important. No attempt has been made to establish any correlation on Clipperton except to point out that beach ridges, resulting from wave action, occur around most of the island, as do reef-front grooves and spurs (all around), also correlated with wave directions (Munk and Sargent 1954).

Tides

No recent published information could be found on tides at Clipperton Island so an inquiry was made at the U. S. Hydrographic Office. The summary of information compiled by Mr. W. E. Malone is quoted below.

"Tidal data for Clipperton Island are not given in either British or U. S. tide tables indicating a lack of recent reliable observations. H. O. Publication 84 does contain the notation regarding Clipperton Island that high water occurs 8 hours and 40 minutes after an upper or lower lunar transit of the local meridian and that the spring rise is 4-$\frac{1}{4}$ feet [1.30 m] while the neap rise is 2-2/3 feet [0.80 m]. The basis for this information is obscure. However, extrapolation from tidal data for surrounding areas indicates that high water at Clipperton Island should occur about 8 to 9 hours after an upper or lower lunar transit of the local meridian and that mean spring tidal range should be between 3 and 4 feet [0.90 and 1.20 m]. It appears then that the information contained in H. O. Publication 84 is fairly accurate. Tidal currents are reported to flood eastward and ebb westward, however, tidal currents are probably dominated or obscured by the general ocean currents."

The information in H. O. 84 (U. S. Hydrographic Office 1951) is the same as that given on H. O. Chart 1680, Clipperton Island. This chart, based on the 1897 survey of P. J. Hennig, Master Mariner, bears the information: "H.W.F. & C. VIII h. 40m. Springs rise 4$\frac{1}{4}$ feet. Neaps rise 2 2/3 feet." The chart also bears arrows indicating direction of ebb and flow currents, ebb arrow pointing westward, flood arrow eastward. Whether this information was collected by Hennig himself, compiled from his observations and those of others such as Fisher (cf.p. 6) or calculated, is not known. Since that time various visitors to the island have made casual observations on the tides, but their results are not available. In 1956, a tide gauge was installed by a party from a Scripps Institution vessel but the gauge functioned only a very short time before it was removed for repairs. In 1958, its emplacement was found to have been destroyed during the 1957-1958 storm.

Ocean temperatures

Schott (1935) presents surface temperatures in maps XX-XXIII, by means of isograms. For Clipperton, the February temperature is over 27°C, that for May over 28°C, that for August over 27°C and that for November 27°C.

Agassiz (1906) includes information on water temperature at stations a little distance from Clipperton (see p. 29). At station 4543 the surface temperature was 79.5°F (26.4°C), the bottom temperature (at 2058 fathoms, 3775 m), 34.7°F (1.5°C). At station 4544, surface temperature 80°F (26.9°C), bottom temperature 34.4°F (1.1°C) at 1955 fathoms (3570m).

Water temperatures are also listed in the results of the Swedish Deep-Sea Expedition (see p. 30) and at station 70 surface temperature was 26.93°C while at 905 meters depth it was 4.83°C (bottom at 3690-3860 m). These figures are included in a table of analyses of sea water at varying depths (Bruneau et al., 1953, appendix, p. VII).

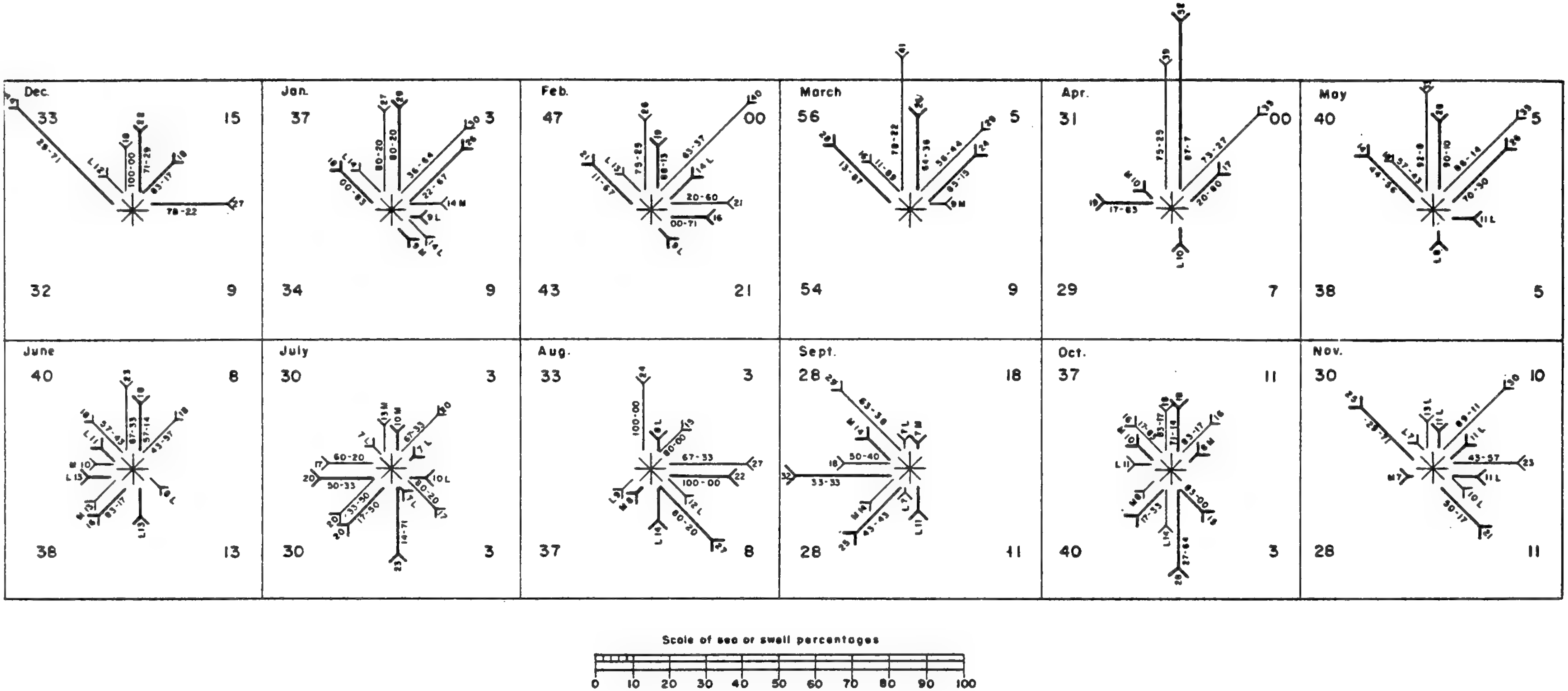
In August-September 1958, the sea temperature measured in a bucket of surface water collected on the reef ranged from 79°F (26.1°C) at 0900 to 84.9°F (29.4°C) at 1100.

Table 5. Sea and swell roses for Clipperton's 5-degree square

The number of observations for sea is shown in the upper left hand corner of the area and the percent of calms for those observations in the upper right hand corner. The number of observations for swell is shown in the lower left hand corner and the percent of calms for those observations in the lower right hand corner.

The sea conditions are represented by the light line arrows, while the swell conditions are represented by the heavy line arrows. No arrow is shown when the percent of directions is less than 7. The arrows point in the directions toward which the seas or swells move. The length of the arrow measured from the center mark, when placed on the attached scale, and the numeral at the tail of the arrow, give the number of times in each 100 observations that the seas or swells have been moving from or near the given point.

When the percent of direction is 15 or over, the condition within the direction are shown along the shaft of the arrow in percentage of low and medium seas or swells, the first figure from the center is always the percent of low. The percent of high seas or swells within the direction is the remainder of the percentage. When the percent of direction is less than 15 but more than 6, the conditions within the direction are shown by the letter L, M, or H (meaning predominantly low, medium or high) beside the percentage figures for direction. The conditions of seas and swells (low, medium and high) within each direction are defined as follows: low seas and swells, those of amount 1 and 2; medium seas or swells, those of amounts 3 and 4; high seas and swells, those of amounts 5 and above.


Dec.
33
15
32
9
Jan.
37
3
34
9
Feb.
47
00
43
21
March
56
5
54
9
Apr.
31
00
29
7
May
40
5
38
5
June
40
8
38
13
July
30
3
30
3
Aug.
33
3
37
8
Sept.
28
18
28
11
Oct.
37
11
40
3
Nov.
30
10
28
11
Scale of sea or swell percentages
0 10 20 30 40 50 60 70 80 90 100

SUBMARINE TOPOGRAPHY

Ocean floor, Clipperton Ridge

The Pacific Ocean between Clipperton Island and the central American coast shows regional depths not exceeding 2000 or 2100 fathoms (3660 to 3840 m) except for some deeper basins and trenches reaching (Middle America Trench) 3000 fathoms (5500 m). The topography of this area has been studied in detail by Menard and Fisher (1958). The same paper describes the Clipperton Fracture Zone, which extends roughly east-west for 3,300 miles (5,300 km) between longitudes 96° and 127°W, and shows for the first time that Clipperton Island is one of the peaks of a ridge, called Clipperton Ridge, 8,000 to 10,000 ft (2500 to 3000 m) high above the ocean floor, and which represents the fracture zone between 107° and 113°W. The roughly east west ridge is about 60 miles (95 km) wide and 330 miles (530 km) long and is bordered along part of its north side by a narrow deep trough. Clipperton is the only feature reaching the ocean surface, but there are at least two other seamounts on the ridge, one to the northwest, the other to the southeast, of the atoll. To the north-northwest of Clipperton another group of seamounts and deep troughs called the Mathematicians Seamount Range occurs between latitudes 13° and 16°N. The paper by Menard and Fisher includes many maps and sections and should be consulted for further detail and general interpretation. Recent exploration of the Clipperton area thus reveals that the atoll is part of an east-west ridge, but remains isolated from other emerged areas, in particular is well separated from the nearest group of islands, the Revillagigedo Is., which belong to a different system, and from the American continent. The features of the ocean bottom and the location of the fracture systems in the East Pacific are very well shown in the maps accompanying a recent article on the East Pacific Rise (Menard 1961).

Ocean bottom

Some information on the character of the ocean bottom in the general area of Clipperton can be derived from the records of the *Albatross* Eastern Tropical Pacific Expedition of 1904-1905 (Agassiz 1906). On the return part of the voyage the *Albatross* sailed just to the east of Clipperton. Stations 4543 at 8°52'2"N and 108°54'W and 4544 at 10°38', 106°47'6" are the nearest to the island. At station 4543 at 2058 fathoms (3775 m) the bottom sample was described as "rd. cly. dk. choc. br. stky. M., few glob., many sm. blk. Mang. part., few Rad., Sponge spic., transp. min. crys. mass of yel. floc. mat." At station 4544 at 1955 fathoms (3570 m) the bottom was described as "stky. dk. choc. br. M., many blk. Mang. part." In the general discussion and in plate 3 (character of the bottom) the Clipperton area is at the limit of a zone to the south and west, where manganese nodules are very abundant, and one to the northeast of "brown and green mud." It is also beyond the northern edge of the area where radiolarians are found, and north of the zone where diatoms are abundant, which zone corresponds well with the cold waters of the Humboldt current (p. 6).

More recently (1947-1948), the Swedish Deep-Sea Expedition explored the Eastern Tropical Pacific with another Albatross and collected information, including soundings of various types and bottom cores, near Clipperton (Pettersson, pp. 50, 117 and pl. I, 1957). Among the many papers collected in the Expedition's Reports, that of Arrhenius (1952) concerns the ocean bottom of the Eastern Tropical Pacific and the Clipperton area in particular (station 70, Sept. 20, 1947, core 47). From his very detailed studies, Arrhenius recognizes (pp. 189-190) various environmental subdivisions in the East Equatorial Pacific, represented in a map included in each part of his work (Figs. 1.0, 2.0, etc.) Clipperton falls in the North Equatorial Carbonate Facies of the East Pacific Ridge, with a calcium carbonate content of the surface sediments between 50 and 75% (map, fig. 1.1.3.1. p. 14). Core 47 (9°14'N, 109°39'W), from the top of a seamount near Clipperton Island, is described in detail pp. 133-136 and in pl. 2.47. While the core was unsatisfactory for Arrhenius' general correlations of geology and paleobiology of the East Tropical Pacific, it is interesting in the study of Clipperton Island. Arrhenius summarizes his study of core 47 as follows: "Core 47 consists of chalk ooze /Globigerina/ with a few marl ooze layers. The topography of the surroundings, the lack of normal stratification, and the faunal composition make probable that redeposition strongly influences the sequence. The redeposited material appears partly to be of shallow water origin. This is understandable as high peaks rise from the East Pacific Ridge in this area, some of them extending above or close to the surface of the sea (Clipperton Island and Germaine Bank).

"The manganese present is to an unusually high degree concentrated to macroscopic nodules. As a result the blackness of the deposit is comparatively low and the hue yellowish."

Undersea mountain

No information is available on the mountain upon which Clipperton Island is perched beyond the data given by Menard and Fisher (1958). Their fig. 3 shows the 1400 fathom (2560 m) contour surrounding the base of the Clipperton mountain and that of another seamount to the northwest. The Clipperton mountain is elongate in a NW-SE direction which is also that of the longer axis of the atoll on top of it. According to the same figure, the emerged atoll is located in the southeast part of the mountain top. This had been suggested by earlier fragmentary observations: for instance in 1942, the USS Atlanta reported the 500 fathom (900m) curve as being about one mile off the southern half of the atoll and twice that off the northern half. The existence of submerged peaks to the north-northwest was also reported by the 1957 U. S. Hydrographic Office survey (Obermüller 1959, p. 48).

The general slopes of the mountain form the asymptotic curves commonly found on atolls, but nothing is known of their aspect, detailed relief or composition, as there has been no dredging or detailed sounding along them. The only undersea mountains that have been explored in some detail are in the northern Marshalls (Emery et al. 1954).

Upper slopes and terrace

Some information on the upper part of the underwater slopes of Clipperton was collected during the 1958 survey by the marine biologists equipped for diving (Allison 1959a, 1959b, and personal communications). The intertidal reef flat slopes off at its outer edge to about 6 m, forming the reef-front (also called fore-slope). This feature is cut by deep grooves or channels. At the base of this steeper part the slope flattens out somewhat and a surface a few hundred meters wide extends outward and down to 12 or 18 m depth. This has been termed the submarine terrace. It was observed all around the island, but varied in width, becoming narrower on the north side, to the west of the northeast sandwash. At the edge of the submarine terrace, the slopes become more precipitous, and have been estimated as between 25° to 40° or even 60°. The divers were able to make some observations down to 40-45 m along this steep outer slope. Its surface is very rough with channels and crevices around the loosely-piled coral heads and boulders. Some boulders are loosely cemented to the slope and slides can be started by loosening the cement.

The marine biologists found that, while some coral and algal growth occurs on the reef front and submarine terrace, it is at the edge of the latter and on the outer slope just beyond that organisms are most abundant and luxuriant. That area was reported as 100% covered with living corals.

It is very unfortunate that these extremely valuable observations could not have been extended and documented by soundings and by dredging, and it is to be hoped that such work will be included in future studies of Clipperton. The discovery by the marine biologists of a submarine terrace around Clipperton is of great interest in view of the fact that similar shallow terraces have been well mapped at Bikini (Emery et al. 1954, p. 68 and pl. 68), Eniwetok (p. 95) and Rongelap (pp. 109, 191, pl. 71). The average depth of their edges are of the order of 45 ft (14 m) (Bikini), 40 ft (12 m) (Rongelap) or deeper (8-12 fathoms) (15-18 m) at Eniwetok, where the terrace has been called 10-fathom terrace. The Bikini and Rongelap terraces have a maximum width of 360 m, that at Eniwetok reaches 3500 m between some of the reef projections. A 10-fathom terrace has also been reported, although not described in detail, in Newell's study of Raroia atoll in the Tuamotus (1956, pp. 334, 341), and is apparently found around other atolls, such as Ifaluk in the Carolines (Bates and Abbott 1958, Tracey et al. 1961), and along other coral reefs.

In the northern Marshalls the distribution of live reef forming organisms on the slopes has been described by Wells (1954, p. 398). Little is known of growth on the reef-front, but apparently few corals grow in this zone, while beyond the 10-fathom terrace growth is more luxuriant. Growth on the terrace is poor probably because it is an area of deposition of debris. Tracey et al. (1948) suggested this explanation for Bikini. These observations cannot be compared in detail with those made at Clipperton but similarities are evident.

Interpretation

In the northern Marshalls, the 10-fathom terrace, which occurs also along lagoon shores, has generally been interpreted as representing an ancient erosion surface, formed during a glacial epoch when the ocean level had been lowered, and upon which a reef grew during the post-glacial period following, when the ocean became warmer and its level rose slowly. This interpretation is confirmed by the fact that in the detailed examination of the cores taken in the drill holes on Bikini islet, sections at depths corresponding to the level of the terrace contain shallow-water organisms, some of them in position of growth and indicating lagoon edge or reef environments (Emery et al. 1954, pp. 215, 224, 257.)

Reef

In a typical atoll the reef is the upper, flat part of the limestone structure capping the undersea volcanic mountain. It usually reaches the intertidal zone and is the seat of dynamic phenomena affecting the atoll: erosion and growth. In most atolls the reef, if not circular, is at least a closed geometric figure encircling the lagoon. The reef may be depressed in some places, forming relatively shallow passages or, especially in some very large atolls, may be interrupted so that deep openings occur. In some atolls, the reef extends at about the same level all around the lagoon and, while there is some water transport between ocean and lagoon over the reef between islets, such inter-island channels are very shallow and cannot be used by boats. In the majority of atolls, dry land consists of islets, discontinuous little patches scattered along the reef surface. Such islets are of two main types (Fosberg and MacNeil 1956): some are only small mounds of unconsolidated debris piled up directly on the reef, others have a core of reef rock forming a sort of obstruction around which the loose material is accumulated (Tercinier 1955, p. 98). Such cores are usually erosion remnants of a higher reef surface the greatest part of which has been destroyed.

In the case of Clipperton Island, a closed oval-shaped continuous reef is topped by a continuous land area. None of the closed atolls has been well studied, and the reasons for the occurrence of a few atolls with a continuous land strip have never been examined in detail. Of some of these atolls, various authors have said that they have been uplifted, and while this may be true in some cases, in others there seems little factual evidence demonstrating uplift. "Uplift" and "raised" are here used to mean only absolute uplift due to a change in the sea-floor in the vicinity of the undersea mountain, excluding the relative change in height in regard to ocean surface which is brought about by changes in ocean level. There is no evidence that Clipperton Island has been raised and no reason to think that its continuous land rim occurs as a result of uplift. I suggest that its closed form may be a reflection of its position in the ocean. The best known of atolls, the northern Marshall Islands, are very strongly asymmetric, a line separating two very different windward and leeward "sides." This line is perpendicular to the resultant of certain vectors,

the more or less constant directions of predominant winds, waves, and currents. The asymmetry does not affect so much the shape of the atolls as the characters of their reefs: the location of openings in the reefs, of islets on the reef, of areas of maximum growth and other such features.

Clipperton Island may be looked upon, on the contrary, as being to a certain extent radially symmetric, because the predominant winds, waves and currents vary throughout the year and fail to form the sort of oriented "field" which surrounds assymetric atolls. This explanation may fit other atolls with a continuous land rim and its applicability will be studied. If this theory is valid for Clipperton Island, it may explain, not only the presence of emerged land all around the atoll, but some ways in which the reef differs from the reefs of many well known atolls, particularly the northern Marshalls.

Around Clipperton Island, the reef flat lines the shore in a regular belt, but with some variation in width. The greatest width, about 130 m, is at the south corner of the atoll and the reef tends to be narrower on the east side of the atoll with a minimum width of about 50 m. During my stay on Clipperton the reef was almost always under some water at low tide. Living corals cannot survive long out of water but in some atolls coral heads or massive algae are sometimes left dry for very short periods by the receding tides. This was only once observed at Clipperton but probably occurs during some spring tides. Landward, the surface of the reef is often covered with sand, especially opposite the sand washes. Coral patches extend over some of the area. Seaward, coral colonies and various algae occupy the reef surface. The striking characteristic of the Clipperton reef is the practical absence of an algal (or "lithothamnion") ridge. In atolls such as the Marshalls or Tuamotus, the seaward edge of the reef, at least on the windward side of the atoll, rises conspicuously in a rough ridge, of a bright pink color, principally made up of massive coralline algae. At low tide this ridge can be seen very well. Immediately on its landward side a moat of slightly deeper water separates it from the main part of the reef flat. At Clipperton, this ridge is very poorly developed and when observed from a distance the edge of the reef is marked only by the breakers. However, the marine biologists who were working on the reef-flat or diving outside the atoll noted that the outer edge of the reef was slightly raised, with a vigorous growth of corals and algae. The deep grooves and channels, observed by the divers on the reef front and mentioned earlier, rise to the edge of the reef, and form surge channels. On the vertical air photographs of the atoll the surge channels can be seen well, and appear to have approximately the same importance all around the island. In other atolls, surge channels cut through the algal ridge, and form passages, often roofed-over, between pillars and masses of fast-growing coralline algae, and through which the surf rushes toward the reef, and the backwash retreats. At Clipperton, the surge channels cut through the slightly raised reef edge, but they were not studied in detail. The greater amount of dissolved gasses in the breaking waters is no doubt responsible for the more active growth at the edge as is believed to be the case in other atolls.

At low tide, the reef flat at Clipperton Island can be seen as strewn with a great many boulders which were probably torn off the slopes of the reef and thrown up by storm waves. These boulders are of various sizes,

mostly less than a meter in diameter, which is generally rather small compared to those on some other atolls. They occur all around the island but are especially abundant and concentrated in certain areas, such as near the north corner where they form a boulder field that lies opposite the gravel ridge on shore. The boulders are colored brown or partly bright green by various algae and many organisms grow on their lower parts, including sponges, encrusting Foraminifera, corals, many algae, molluscs, as well as associated free living animals.

When an atoll reef dries or almost dries, at low tide, patterns of erosion, channels, cracks, pools or other forms normally can be observed. Such patterns were not recognized at Clipperton, partly because most of the landward side of the reef flat is covered with fine sand. Much of this is only a thin film or is replaced by pebbles or cobbles, with interstices filled with sand. These areas can usually be identified by the abundance of algae growing on the pebbles. In certain places however, the reef is bordered by beach rock, which will be described below, and occasionally the beach rock is located in such a way that it is the seat of active erosion and forms typical erosion ramps. Such a ramp occurs along the northeast coast. A slightly sloping slab of beach rock several meters wide stretches between reef and beach and exhibits a polished surface unevenly pitted into shallow, rounded depressions, which are probably the site of mechanical erosion (abrasion). The walls between the depressions are not sharp and cutting as sometimes happens on other atolls, but form gently rounded, low shoulders between pits. Some of the pits are joined together in shallow troughs, elongated in a beach-reef direction. The landward side of the ramp borders on the sandy beach and, at times, sand may be deposited over the ramp and hide it from view. The reef side of the ramp is occupied by algae, forming a brown felt or an orange crust. In some areas along the northeast coast of the atoll pieces of this ramp, undercut, broken and loosened by storm waves, have been displaced and rest on top of the sandy beach. In some parts of the atoll, small remnants of a ramp occur which may have been derived from an old reef surface rather than from old beach rock.

Presumably the reef flat surface extends lagoonward under the island sediments, but nowhere inland did I see any indurated material that could be interpreted as an exposure of this surface. Obermüller (1959, p. 50) makes the same remark. At the lagoon edge, a gently sloping, irregular surface of consolidated rock sometimes forms the bottom for at least a little distance under water; what was seen of this seemed little different from the consolidated phosphatic rock above water, and none of it suggested either a reef surface or lagoon beach rock. Judging from the sample brought back (no. 35), broken from a rough place in this surface, it consists of coral debris indurated with a phosphatic cement.

SURFACE FEATURES OF LAND STRIP

Outer shore

Beaches

Above the reef flat, often edged by beach rock, the island is surrounded by a beach of sand or gravel; usually this is a narrow stretch of fine coral sand, pinkish in color, sloping up from the beach rock exposures. Above it in most areas is a ridge of white coral fragments, in places branched even-sized pieces, elsewhere larger cobbles or boulders. In some areas, as on the southeast part of the island, south of the Hook, there is no sand beach but a steep ridge of coral fragments rises directly above the reef flat. In other places, the beach is wider and steeper and forms the whole oceanside slope, up to the crest of the land strip. In 1958, along a region 430 m long of the narrow northeast side of the atoll, sand had washed all the way from the ocean across the land strip to the lagoon. The beach here was lined oceanward by well-developed slabs of beach rock and on the landward side merged into a lagoonward sloping area, but the break in slope was faint, since the highest point was less than 1 m above estimated mean high tide level. This area will be referred to as the great sand wash. The sand was stained green at the surface and for the first 0.5 cm in depth, by blue-green algae. Below it was pale pink. Transverse lines of pebbles stretched across the wash, probably marking the direction of water flow. Any doubt that the ocean waves poured into the lagoon at this place when it was denuded of vegetation between November 1957 and May 1958, would be dispelled by the fact that marine shells, drift seeds and drift pumice had been carried across to the lagoon edge. In the lagoonward part of the wash two low rocky ledges stretched parallel to the shore. Their upper surface was hidden but the sand had been removed from under their lagoonward free edges, so that each protruded slightly over a longitudinal depression several decimeters deep. That nearer the lagoon shore formed a moat full of water green with algae.

There were several other, less spectacular, sand washes. Near the East corner of the island, the beach sand reached up to the crest of the island and spilled over the land in a very gentle (about 3°) lagoonward slope. The beach here was especially mobile and, at the time of our visit, one day formed a slope of about 12° for most of its width, topped by a little vertical cliff, about 30-50 cm high, cut in the sand at high water mark; on a later day the cliff had disappeared and the beach sand sloped regularly up from the ocean to the break in slope. On the southeast side, along Rock Bay, sand also spilled over from the beach onto the gentle lagoonward slope; this sand wash probably marked the location of one of the ancient passages into the lagoon, as the great northeast wash marked the other. Still another area occurred on the southwest side: The sandy beach occupied the whole width of the area between ocean and land crest and the dry land was again covered by a stretch of sand gently sloping to the lagoon.

In all these places, the sand was white or pale pink-orange where it was usually washed by seawater, and above the reach of ordinary waves the pink sand was hidden under a layer, 0.5 cm or more thick, of sand stained green by blue-green algae and sometimes slightly compacted into a friable crust. Except for this algal material, and for a very few seedlings of Ipomoea pes-caprae as well as occasional seedlings from drift seeds, there was no vegetation in 1958 on Clipperton Island beaches. However, on photographs taken in 1938, 1943 and 1957, Ipomoea vines can be seen to creep down the beaches from the land strip, at least on the east side of the atoll, and in 1958 masses of dead vines hung over the undercut edges of the land strip. The beaches are very mobile and even their upper regions, which could be called storm beaches, are constantly changing under the action of frequent storm waves. In contrast to this mobility, the relative permanence of the sand washes is worth investigating. Two of them mark the former shallow openings into the lagoon and most of them can already be seen on photographs taken in 1935 and recognized in older descriptions. They evidently correspond to particular configurations of the modern reef and underwater slopes and probably also of ancient, higher reef flats, that facilitate erosion and sand deposition but not gravel or boulder accumulation.

Beach Rock

Typical exposures of beach rock are well-marked along most of the seaward northeast coast of Clipperton. They can be clearly seen on the air photos of 1943, and were followed on the ground along most of their course. On the same photos, a dark line about the middle of the southeast coast may represent beach rock, but in 1958 this area was covered by a deposit of boulder or cobble gravel and no consolidated material was seen. Beach rock was also observed in 1958 by other members of the party (personal communication) on the southwest coast, after a storm washed off the coral sand and gravel which had accumulated over it. The several slabs had approximately the same slope as the present beach, and pieces of iron, including part of an old anchor, were embedded in it. Nothing that could be interpreted as beach rock was observed anywhere on the lagoon shore.

Along the northeast side, some little distance northwest of the camp, the beach rock presents the following aspect: the beach consists of a thin layer of sand, occasionally removed and exposing a pavement-like layer of white rock. Over part of this pavement, lies another smooth slab also apparently in situ with a small overhang on its landward side. Further north, the upper surface of this slab becomes pitted with shallow pot holes and takes on the aspect of an erosion ramp. Over it lie other thin, broken and displaced slabs, very sonorous when hit with the hammer. A piece of one was collected (no. 17) which seemed to be softer on its undersurface than on top. Some small tufts of green algae were attached to its top surface. Other slabs were colored orange-brown by a felt of algae (no. 306). All the beach rock slopes oceanward, with a general dip of about 10^{o}. Some slabs are cracked parallel to the coast line. In spite of the sandy nature of the beach, almost all of this beach rock is

not a sandstone but a conglomerate of small fragments of coral and material from a few other organisms, such as shells, with a sandy cement. Therefore beach conglomerate is the appropriate term for this rock. The thin, sonorous slabs are very like typical beach sandstone except for the difference in texture.

Continuing along the ocean side, northwestward of the area just described, similar groups of slabs occur, with the lowest one again forming a white pavement about 4 m wide in places covered with beach sand. Above this and immediately landward of it lies a thicker strip over 6 meters wide of coarser conglomerate, also sloping oceanward, with a dip of 17° in its lower part. Its lower edge is undercut and dissected in deep scallops, perhaps somewhat overlapping the pavement. Numerous blue-black Littorina shells are attached to the crevices, as well as a very few specimens of Nerita. Because of its dip and because it is well indurated at its lower edge and over most of its surface, this thick bed shows at least a superficial resemblance to typical beach conglomerate. At its upper edge, in its texture and poor induration, it shows a strong resemblance to the flat beds of coarse, poorly indurated material lying to landward and extending across the island. Unfortunately no samples were collected. The material might be interpreted as resulting from the same induration process as formed the flat beds to landward, but applied to the seaward face of a beach ridge. If, on the other hand, it is interpreted as beach rock, the fact that it stretches well above present high tide levels would suggest that it was formed during a previous higher stand of the sea. The thin slabs and the pavement below this layer are intertidal and probably represent modern beach rock.

The area of the island here described is part of the land strip which had recently been affected by a violent storm. It may be as a result of this that a long depression, parallel to the shore, about one meter deep and lined with broken coral gravel, was formed between the thick sloping bed just described and the landward flat ledge of indurated gravel. The highest elevation in this general area is 2.25 m above estimated mean high tide level. The longitudinal depression flattens out as one continues to walk northwestward along the beach and, farther on, only a regular slope of loose gravel stretches from the flat landward ledge of consolidated gravel to the thick beach rock; still farther, the latter disappears under the gravel slope which extends all the way down to high water mark.

The thick elevated "beach rock" was not seen in any other part of the island but stretches of it may be hidden under some of the beach ridges.

Along much of the northeast coast where intertidal beach rock occurs, broken and displaced slabs, many too heavy to be moved by one person, are found at the top of the beach which is presumably reached only by storm waves, and are also strewn over the land area. These dry slabs are smooth and white, some with a marble-like glitter. Generally, like those in situ, they are made up of coral fragments of varying size, but none were fine enough in texture to be properly called beach sandstone (cf. sample no. 28).

Land

Beach ridges

Seaward of the Naturalists' Camp, there is no well-defined boulder ridge. Boulders and slabs of beach rock, some of them quite thick and heavy, are scattered at the top of the sandy beach, and above it rises the cliff-like edge of the consolidated rock layer which forms the land area: this is undercut and evidently has rather recently receded under the action of storm waves, as dead Ipomoea vines hang over the cliff; they must have formerly extended farther toward the ocean. Elsewhere around the atoll, especially on the south and west sides, outer beach ridges are well developed and consist of well-sorted coral fragments, most commonly about 7-10 cm long. The sorting is apparently facilitated by the fact that the coral fauna is rather poor, and in most places practically the whole mass of gravel comes from one species or a small number of related species.

Around the north corner of the island, the ridge includes material of more varied size and also from a greater number of species. The range is from pebbles to cobbles and a few boulders. In that area, the beach ridge is an enormous one and extends inland into a narrow pebble and cobble field, which may have been reworked somewhat at a recent date, as some of the blackened cobbles have been displaced and some of their lighter undersurfaces are exposed. In the same area, a secondary ridge or gravel bar has been formed on the seaward side of the reef flat, and cuts off part of the flat as a reef pool. This is reminiscent of a feature observed on Jaluit atoll after the typhoon of January 1958 (Fosberg, personal communication and Blumenstock, ed., 1961). This secondary ridge may be a fugitive feature and will perhaps move landward until its material is added to the main ridge. This is what is happening on Jaluit (Blumenstock et al. 1961). There are areas on the southwest coast where the beach ridge of even-sized gravel has a double crest, with a slight longitudinal depression, indicating that the ridge may have been added to secondarily. However it is not absolutely sure that this double-crested ridge is natural, as further north, along the main coconut grove and the abandoned quonset village, the ridge has obviously been artificially added to, in order to provide greater protection for the camp. Double crested ridges, however with very different profiles, are well known from other atolls (Fosberg, personal communication).

All the beach ridges are white on their ocean facing slopes. Their flat tops, sometimes depressed in the center in the case of the double-crested ridges, and their shorter landward slopes are blackened. The line of demarcation between blackened and white coral is sometimes very sharp. The discoloration is due to microscopic algae. The under surfaces of the coral pieces are usually paler and range from white to dark gray. In some areas and under certain lighting conditions, the dark coral looks very much like a desert of black volcanic lava.

On the Isthmus leading to Clipperton Rock, and more particularly on the land strip parallel to it on the other side of Rock Bay, the pigs had worn conspicuous pale trails in the dark gray coral gravel. These trails can be seen very well in the same area on the air photos taken in 1943. It will be interesting to see how long they will persist now that the pigs are gone.

Land surface

As mentioned earlier, the land slopes from the top of the beach ridges lagoonward all around the island. Generally the slope is steep at first, along the landward side of the beach ridge, then becomes more gentle. Obermüller (1959, p. 50) estimates the latter as 5-10%. In many areas the grade is slight but a series of step-like ledges bring the level down. The surface of the land strip may consist of loose or consolidated material.

Unconsolidated material:

The sand washes and the inland slopes of the gravel and boulder ridges, as well as the boulder fields, have already been mentioned as landward extensions of shore features. Other areas of the land, generally rather flat, are sandy or covered with a very weakly developed soil and often sprinkled with a thin layer of coral fragments. The predominant soil is a mixture of small coral gravel and pale brown silt (cf. samples 5, 34, pp. 57, 58), shown by analyses to be highly phosphatic. In places this may be covered by gravel sheets of varying thickness, by linear ridges or stripes of loose blackened coral fragments, or by a layer of sand. Where the consolidated material is exposed, a thin irregular deposit of sand or scattered gravel usually lies in depressions or on the surfaces. Of course, due to the extensive disturbance by guano digging, little can be said about the natural characteristics of the soil profiles or the original disposition of the older loose sediments.

The more characteristic physiographic features of the land are formed by consolidated sediments. These occur in three main aspects: ledges or steps, pavements, and cliffs at the lagoon edge.

The ledges:

There are actually two kinds of ledges, both probably exposures of the same flat or almost flat consolidated beds. The first type is exposed only on the ocean side of the northeast land strip: Stretching between Naturalists' Camp and the beginning of the sand wash, the seaward margin of the flat bed just mentioned forms a wide ledge with an abrupt vertical or overhanging escarpment, 0.5 to 1 m high, but with the lower part covered by gravel deposits. This ledge occurs opposite and just above the thick coarse oceanward-sloping conglomerate described on p. 37. The upper surface of the ledge has a scarcely perceptible slope toward the lagoon. This exposed surface varies in width from almost nothing to perhaps as much as 1/3 or 1/4 of the width of the land strip. In most

areas, the consolidated layer is covered landward by a storm-deposited sheet of white gravel composed of somewhat rounded coral branches (see p. 71). Very possibly, the consolidated bed, and its oceanside edge forming the first type of ledge, were exposed at the time of the same storm by the removal of loose material and elsewhere are hidden under the beach ridges.

Around the far greater part of the periphery of the atoll, except for the sand washes, runs an interrupted and irregular series of a second type of very low concentric ledges of what appears to be the same material as the first type. Their scarps face the lagoon and are never more than 2 or 3 dm high. Where they are well developed, as on the northeast side just west of the wreck and in some areas of the southwest side, the ledges, from the lagoon shore, look like the bleachers of an amphitheater and one can walk up them as a series of irregular steps. They are often arranged in groups, several steps very close together, then a wide pavement and another group of steps above it. The free edges of the steps often form overhangs sheltering cavernous spaces inhabited by many land crabs. Seen from below, the free edges of a group of steps look somewhat like those of bedded beach rock slabs, but as far as can be told from their irregular surface the ledges do not dip as beach rock would. This agrees with Obermüller's observations (personal communication and 1959, p. 50). Seen from above, the ledges show a consolidated surface often covered in places by loose sand or fine gravel, especially near the base of the next upper ledge. Plants sometimes grow on the surface of the ledges, particularly in this loose material.

In some areas, for instance near the East corner, the lines of ledges are rather regularly parallel to the shore. Elsewhere, they may follow the line of the shore for a while then swing inland away from it. Near the south corner at the base of the Hook there is a vast area where vegetation is rather sparse, and where low ledges are very conspicuous. They form a complicated pattern of arcs which have little relation to the present lagoon coast line. On the other side of the Rock, some series of low ledges swing away from the Isthmus to form the low rocky Thumb Point. Some of the ledges can be followed for considerable distances and it is not impossible that by digging some could be shown to extend more or less continuously all around the island. Measuring their height in relation to a fixed point (for instance the marker on top of Astro 1957) and mapping their courses might give useful information and help understand their origin. Where they were shown to be absent it might be assumed that a passage once existed, now filled with loose sediments.

Exposed pavements:

These are especially well developed in the southern part of the atoll, i.e. on part of the Isthmus and on Thumb Point, and on the other side of the Rock, at the base of the Hook. In most areas, they appear as the top surface of ledges, in others they are less obviously connected with them, and disappear under loose material or denser vegetation. Their surfaces often seem horizontal. In places they are rather smooth, more often they appear dissected by erosion, particularly by rain water, into a miniature karst surface a few centimeters high. According to Obermüller, they represent a rich phosphate deposit.

Lagoon shores

Lagoon cliffs:

When they reach the lagoon, groups of ledges and pavements may end abruptly above the level of the water forming "cliffs."* Both on the northeast lagoon coast, a little north of Naturalists' Camp, and almost diagonally opposite, on the southwest side of the atoll, north and south of the coconut groves, lagoon cliffs occur which are up to 1.50 m high above lagoon level. The rock forming these cliffs is uneven in structure and hardness so that the cliffs may present overhangs or, on the contrary, be cut back at the top. Commonly they have been worn by erosion and blocks have fallen off from the overhangs, or harder parts have occasionally been left in place in front of the new cliff face as "mushrooms." These small remnants, surrounded by water or by loose gravel, are much used by sea-birds as nesting sites as they afford protection from the pigs. On the northeast side, such cliffs extend for a long distance, arising somewhat back from the water's edge and separated from it by a slope or beach of gravel. Some of this probably originated from the erosion of the cliff and some may have been deposited by the 1957-1958 storm. The cliff was apparently much damaged by this storm and large overhangs of its upper, more firmly consolidated, part lay broken off and tilted near the lagoon shore.

Other lagoon shore types:

Along most of the lagoon shore, the land is not so high above water level and rocky overhangs a few decimeters above water level replace the cliffs. They are often hidden under a thick blanket of *Ipomoea pes-caprae*. They appear to consist of the same type of consolidated rock as the upper part of the taller cliffs. Elsewhere, as in the vicinity of the Rock, a low pavement may extend to the water's edge, forming a very low rocky shore. Consolidated rock or pavement may continue under water for some little distance into the lagoon. In other areas, fine sediments or plant debris accumulate on the bottom at the edge of the lagoon. Mud flats may also form the lagoon shore. Because of the constantly fluctuating level of the lagoon (tides and perhaps rainfall and evaporation) their width varies and their material may be reworked with the movement of the water. Often, however, they are held by vegetation, i.e. beds of sedges.

Near the east corner of the island, and for a long distance southward, the consolidated rock layers and ledges swing inland and a low lying area of generally fine sediments spreads between them and the water. The lagoon shore here is of fine white sand or small gravel forming a narrow beach or more often arranged in a low (a few decimeters) and narrow beach ridge. Lower land often lies behind this ridge and may be covered by stagnant pools of water and occupied by sedges. Strong

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* "Cliff" perhaps gives an exaggerated idea of such low features, but it describes well their abrupt faces, and avoids confusion with some other miniature atoll landforms.

lagoon waves during storms keep reworking the ridge and at times cut channels across it and flush the pools. The sand seems to extend from the beach for some distance under water into the lagoon. Because of the very gentle slope, the lagoon water covers and uncovers sand flats with every small change in water level. During our visit, there were many wind and rain storms from the southwest which drove great quantities of water plants, principally Najas, toward the eastern half of the atoll. They formed thick masses in the shallow edge of the lagoon and were often deposited in windrows along the beach and beach ridge. Some dried up lines of this material on the top of the beach ridge, or curling crusts of lagoon algae some distance behind it in the mud flats, indicated that at times the lagoon must reach higher and spread farther inland than we ever saw it. The sand beach ridge had probably been relatively stable for a while before our visit, as Ipomoea pes-caprae vines were creeping across it from a large patch inland. The sand was alive with tiger beetles.

Mobile sandy beaches and low beach ridges occur also on the north part of the northeast shore, at the lagoon edge of the great sand wash. Here sand or gravel bars often form scallops sometimes closing off temporary ponds, especially at low lagoon levels. Between the camp and the great sand wash, gravel bars often occur at the foot of the cliffs or, at Green Point, along low lying ground, and may cut off from the lagoon some stagnant ponds or moats usually full of algae. These bars occasionally are cut by channels and the ponds or moats flushed by lagoon water. The gravel is similar in size and appearance with that of the recent gravel sheet and probably was deposited at the same time.

Clipperton Rock

In the southeast part of the atoll, a narrow tongue of land called the Isthmus juts into the lagoon in an east west direction and at its free western end rises the irregular volcanic mass called Clipperton Rock. Its height has been variously indicated as from 19 m to 29 m or even 80 m. The latter was estimated from the distance at which the Rock disappeared from view, and is certainly wrong. None of the recent scientific and other surveys included measurements of the Rock, as far as could be ascertained. The most recent figure that is based on well-described surveys is that of 29 m above ocean level obtained in 1935 by the officers of the Jeanne-d'Arc (Lacroix 1939, Gauthier 1949) but it may be a bit high. Many visitors have been struck by the resemblance of the Rock to a distant sail, or from closer up, to a ruined castle. Indeed these are apt comparisons.

The base of the Rock is roughly lozenge-shaped, with its long axis in a general east west direction. The highest pinnacle is near the center of the mass. Seen from the Isthmus, the east face rises as an almost vertical wall, as does the north face when seen from the lagoon. As one walks around the Rock, several passages, mostly roofless, roughly parallel and separated by thick vertical walls, are seen to lead into it. The floors of these passages slope upward and are covered by fine material

mixed with coral pebbles, guano, feathers and other debris (cf. sample 15 p. 56). Some of the passages can be followed completely through the Rock. The parallel walls separated by open passages are well shown on some of the photos taken from helicopters.

From a superficial examination, the most obvious possible origin for the Rock is that it is part of the crater of the undersea volcano, and this was suggested by Geikie (in Teall, 1898, p. 233). The detailed study of the lithology of the volcanic material, and of descriptions and photographs of the structure of the Rock, led A. Lacroix (1939) to describe it as an extrusive dome, comparable to that of Bogosloff, and formed in the same manner as that of Montagne Pelée. This would make it a cumulo-dome or better, a plug dome (Cotton 1952), that is, a mass of very viscous acid lava slowly squeezed out of the volcano and cooled without ever flowing. This is how the Pelée spine was formed. The Bogoslof volcano in the Aleutians forms small islands or rocks in the ocean in this way. The main difference between Bogoslof and Clipperton is in the fact that the former is in an unstable and very active area, and its various peaks and islands have been formed and have been destroyed by erosion or explosion within the last century (Byers 1960). The Pelée spine also was destroyed soon after its formation. By contrast, the Clipperton volcano has been inactive for a very long time and the Rock has been stable for at least as long as it has taken the coral cap to form over and around it. It might be more evocative to compare Clipperton Rock with some land domes such as some of the trachyte domes or phonolitic plugs locally called "sucs" in the French Massif Central (Williams 1932). Obermüller, after studying his samples and examining the Rock itself concurs with the interpretation of Lacroix.

Nothing is known of the roots of the Rock, nor of the thickness of the limestone which caps the other parts of the undersea mountain.

The very striking ruin-like aspect of the Rock, as seen on photographs or as visualized from descriptions, gives the impression that it is a crumbling pile of loose eroded material. Nothing could be further from reality. When one climbs into the Rock, its massive walls appear as solid and impervious to the elements as possible. There are no joints or cracks, no loose pieces of rock, no areas of scree or talus. To one accustomed to the "rotten" rocks of the Alps for instance this is very striking. It is known of course that the volcanic rock has been modified by the combination of bird guano and rain water and that much of it, to an unknown depth, is more or less phosphatized, but this is not apparent to the casual observer, nor does it result in obvious disintegration of the rock, which is very difficult to break with a hammer. Handholds and footholds are precarious as most of the surface is very slippery, with rounded rather than sharp edges; climbing is made more hazardous by the great abundance of nesting birds who snap at the intruder and can make him lose his grip not so much from pain as from surprise at the sudden attack. Indeed the whole Rock is alive with birds, mostly noddies and brown boobies. Their nests occupy every small shelf, crevice and projection of rock and many noddies also lay eggs on the floors of the passages without any nesting material at all. The generally reddish surface of the Rock is in many places splashed with white guano, often in trickles

below the nests, or is glazed with a white crust. The "corals" mentioned by Pease (1868 p. 201) could not be found. However Obermüller points out that the birds carry coral pebbles to the very top of the Rock as part of their nesting activities, and that in places these might become cemented to the volcanic Rock. Another possible explanation for Pease's remark is the occurrence, in some caverns or along some walls of the Rock, of areas where water trickles down and encourages the formation of a tapestry of green algae, and the deposition of mineral incrustations (cf. sample 16 p. 64) which could be said to look like some coral skeletons.

The base of the Rock, and therefore the manner in which it joins the coral substratum, is generally hidden by piles of coral debris and soil, similar to the material on the floor of the passages, and sloping down to the level of the lagoon. On the south side of the Rock, there is, however, one striking contact between volcanic rock and coral conglomerate. This is a small limestone shelf or ledge a meter or less in width, distinctly undercut to form a notch or nip, 0.7 to 1 m above lagoon level. The upper surface is approximately horizontal, and was estimated at 1.20 m above the lagoon water level. Despite oscillations which are apparently of the order of a decimeter, the lagoon level can be grossly estimated as near mean sea level and this would place the nip within the 5-6 foot (2 m) level (above mean low water) associated with the Abrolhos Terrace of Teichert and Fairbridge (Fairbridge 1958 p. 479). How the shelf was formed and what exactly it represents in terms of past aspects of the atoll could not be investigated but it certainly must have been undercut by lagoon, or possibly ocean, water at a time when the level was higher. Such undercut benches, remnants of ancient higher reefs or coral conglomerates, are common on limestone islands in the Pacific. However, it is often difficult to recognize them with certainty on atolls, and to be sure of the relative ages of various features. In this case the coral shelf is at least much more recent than the volcanic Rock, and one can tentatively suggest that its material may have been deposited and cemented during a post-glacial slightly higher sea-level, and that later the shelf was undercut at a level lower but still higher than present sea. It deserves detailed investigation. On the larger of the volcanic islets located a short distance off the south face of the Rock, another coral limestone shelf is present, almost directly opposite the one just mentioned. This may be part of the same feature, perhaps a bench of conglomerate that extended across the present arm of the lagoon and was broken and undercut. The notch is less obvious on the islet than along the Rock, and the present surface of this bench slopes along the side of the islet from approximately the height of the one opposite down to near lagoon level.

Lagoon

The closed lagoon of Clipperton Island forms a great lake, oval in shape, with an arm on the south side, around the Rock (Rock Bay). In fair weather it is smooth but strong winds can make its surface very choppy.

Lagoon water

Since the time of Griswold's visit in 1861 (Pease 1868), visitors have been surprised to find the lagoon water "fresh" (Taylor 1948) or almost so. There is some indication that it may, in times of drought, become more salty and unpleasant to drink. Some laborers are even reported to have died from drinking it (Slevin 1931). In September 1943 (Byrd 1943) the salt content of surface water was given as 70 grains per gallon (about 1200 parts per million). In October 1956 water was collected at a depth of 10 meters (Limbaugh, unpublished report, 1957) and found to contain 2.97‰ salinity (about 3000 parts per million). Surface water collected in November 1957 (Obermüller 1959) had a salt content of 4 or 5 g per liter (4000 or 5000 parts per million). In May 1958 surface water collected opposite the wrecked LST gave the following (Klawe, personal communication, 1959):

	Chlorinity ‰	Salinity ‰
Bottle 1	2.595	4.71 (= 4700 parts per million)
Bottle 2	2.59	4.69 (= 4700 parts per million)

This water was said to be supersaturated with oxygen, as it was collected in an area full of aquatic plants.

The water collected in August 1958 was analyzed by the Quality of Water Branch, U. S. Geological Survey, and found to have a salinity of 3840 parts per million (see p. 46 for complete analysis). Samples collected by C. F. Harbison in August 1958 and by Conrad Limbaugh in his dives in September, were titrated in the laboratory at Scripps Institution of Oceanography and showed:

		Chlorinity ‰	Salinity ‰
a)	Lagoon (sample slightly murky, slightly yellow, fermented odor, gelatinous substance at bottom)	1.17	2.15(=2000 ppm)
b)	Pond filled with sedges, at base of the Hook [probably after rain]	0.01	0.05(50 ppm)
c)	Lagoon, surface (Sept. 1)	2.36	4.29(4300 ppm)
d)	Lagoon, 4.5 m depth (15 ft) "	2.45	4.45(4500 ppm)
e)	Lagoon, 20 m depth (65 ft) "	17.45	not calculated by the laboratory because of the abundance of sulphites but estimated as 31.5 ‰ (31500 ppm)
f)	Lagoon, surface (green fibrous substance at bottom) (Sept. 8)	2.39	4.35(4300 ppm)
g)	Lagoon, surface (Sept. 17)	2.28	4.16(4000 ppm)

Analysis of Clipperton Lagoon Water

by Quality of Water Laboratory, U. S. Geological Survey

(in parts per million)

Laboratory Number 55153 - Lagoon; Clipperton Island, eastern Pacific Ocean

Date of collection...........1958

Silica (SiO_2)......................	1.2
Aluminum (Al)......................	.3
Iron (Fe).........................	.06
Manganese (Mn)....................	.00
Copper (Cu).......................	.00
Zinc (Zn).........................	.08
Calcium (Ca)......................	65
Magnesium (Mg)....................	133
Sodium (Na).......................	1220
Potassium (K).....................	16
Lithium (Li)......................	.4
Bicarbonate (HCO_3)................	72
Carbonate (CO_3)..................	0
Sulfate (SO_4)....................	80
Chloride (Cl).....................	2270
Fluoride (F)......................	.0
Nitrate (NO_3)....................	20
Phosphate (PO_4)...................	.3
Dissolved solids	
Calculated......................	3840
Residue on evaporation at 180°C.	4370
Hardness as $CaCO_3$.................	709
Noncarbonate hardness as $CaCO_3$....	650
Alkalinity as $CaCO_3$...............	59
Free Carbon Dioxide(CO_2)(Calc.).	18
Specific conductance	
(micromhos at 25°C).............	6690
pH...............................	6.8
Color............................	5
Ignition loss...................	364

Another sample taken at 0.60 m depth (2 ft) by W. Baldwin and J. Wintersteen also had a salinity of 4300 ppm (Baldwin, personal communication). How comparable the different figures are is difficult to say. Even those obtained in 1958 may not be comparable, because of the different methods used in obtaining them, and cannot show definitely whether there is a significant seasonal change. Yet if there is really a marked dry season on Clipperton (U. S. Hydrographic Office 1951) it is to be expected that with continuing evaporation and lack of replenishment by rain water the lagoon might become noticeably saltier.

Lagoon level

The lagoon level has been variously reported as being much lower, or much higher, than the surrounding ocean. One of Captain Taylor's companions studied it and decided (1948, p. 173) that it was "on the mean tide level of the ocean." During our visit the level was oscillating continuously and it was obvious that in addition to possibly minute changes due to heavy rainfall and evaporation, a tidal effect was present. No absolute measurements could be made but generally the lagoon level was never so conspicuously higher or lower than the ocean that an observer standing between the two could notice it on casual observation. There is no doubt, however, that during storms the ocean can pour over low and narrow areas of the atoll rim and add water to the lagoon. This would affect both salinity and level for a while. Seepage through the walls of the undersea mountain eventually brings the lagoon level down but with a lag, and shortly after a storm and paticularly at low ocean tide, the lagoon may appear to lie higher. Some open lagoons are well known to present this phenomenon: in Pokak atoll, Marshall Islands, with every high tide the ocean pours over the reef; at low tide the current out through the narrow opening and seepage do not suffice to empty the lagoon and establish an equilibrium and the lagoon can always be seen to have a higher level at low tide than the ocean.

In an ideal circular island (Wentworth 1947), considered as a porous mass rising through sea water to above sea-level, the fresh water derived from rain forms a lens (called the Ghyben-Herzberg lens) floating on top of sea water and extending downward to below sea level. Tidal effects through the porous mountain push the lens up and down with but little mixing if the tide range is low and the fresh water lens is thick enough. The best known undersea atoll-mountains, Bikini and Eniwetok, have been shown from the drill cores taken from them and from geothermal measurements (Swartz 1958) to be extremely porous. Nothing is known of the Clipperton mountain. Much of it probably is very porous, although the occurrence of the volcanic Rock indicates that part of its mass all the way up to sea level must be of less porous volcanic material.

In an ideal situation, with distilled water versus sea water of a specific gravity of 1.025, the fresh water would extend 40 times as far below sea level as it did above (Cox 1951, Arnow 1954, Tracey et al. 1961). Atoll islets in wet climate areas have shown themselves to be examples of this phenomenon and their ground water bodies form Ghyben-Herzberg lenses, though by no means ideal examples since the water is never pure nor the porosity even. A comparable effect perhaps occurs in Clipperton lagoon.

The slightly salty water rests on saltier, heavier water occurring either in the bottom of the lagoon or in the mountain under it. Unfortunately it was not possible to dig wells, and nothing is known of the ground water on Clipperton. It may or may not be fresher than the lagoon water, and may or may not form a separate water body. Perhaps the brackish water lens extends from the lagoon sideways under the dry land rim as ground water, and the water bodies in both lagoon and island might together be regarded as a single large Ghyben-Herzberg lens. Or the two may function independently. It would be very important to study ground water in wells and to collect lagoon-bottom water samples. Determining how far lagoon and ground water levels are above mean sea level would also help speculate on the depth to which brackish water may extend in the lagoon and in the land.

The scientists who were skin-diving in the lagoon reported (Hambly, Allison personal communication) that the lagoon water was usually turbid near the surface, where it was warm; a clear layer of cold water began at depth of about 6m. In a hole, the total depth of which could not be measured, a layer of inky black water, smelling strongly of hydrogen sulfide, was encountered at 20 meters. It was noticeably saltier (sample e, p. 45).

The numerous dead reefs which occur in the lagoon, especially in its southern half, and rise to near the surface, divide the lagoon into compartments. Even though the reefs must be porous, their presence must impede circulation and mixing.

Lagoon depth and nature of bottom

The maximum reported depth of the lagoon is 55 fathoms (100 m) for a point in the southwest part of the lagoon (sounding by Hennig, 1897, U. S. Hydrogr. chart no. 1680, 1897 ed.) Various French sources quote depths of 100 m, probably based on the same record. If Hennig's figures are reliable and still apply, only a few local areas reach such depths. During recent visits, several parties (Byrd, Taylor) made soundings but the results are mostly not available. On a photo map prepared from the airphotos taken in 1943, the soundings made by Byrd (1943, vol. 1 p. 22) are written in, apparently in feet. On a traverse from Pincer Bay to the east corner, depths from 38 to 60 ft (11.5 to 18 m) are recorded in the open water in the middle of the lagoon. Another traverse due south from the North corner gives a miximum depth of 32 ft (9.7 m) for the northwest part of the lagoon. The traverse from Naturalists' Camp south to the Rock includes the greatest depths from 42 ft (12.8 m) just north of the Rock to 120 ft (36.5 m) in open water near the East corner. Where the traverses pass over the submerged lagoon reefs, the recorded depths are between 4 and 7 feet (1.2 and 2.1 m). In 1958, the biologists dived to depths of 20 or 25 m. Much of the lagoon is probably between 10 and 20 m deep with deeper holes, and becomes shallow as shores are approached. Nowhere is the lagoon very deep close to shore. There the bottom is sandy or muddy, or made up of consolidated coral rock extending from the shore. This cannot be observed very well, however, as the water is generally turbid and great masses of water plants, living or dead, obscure vision. Away from the shore, however, in areas of deep and open water, the bottom is described (Hambly, Allison, personal communications, Limbaugh unpublished report, 1957) as follows:

Past the fringe of plants growing in thick muddy sediments, the layer of sediment becomes thinner, with occasional sandy patches. On such sand and on some coral pinnacles dead marine lamellibranchs (Codakia sp.) and gastropods (Cypraea moneta, Hipponix antiquatus) can be found in place.* Farther into the lagoon, in deeper clearer water, thick layers of sediments are found. Occasionally, coral pinnacles rise clear of this muck, which covers the bottom around them. E. C. Allison (in lit.) writes: "coral ridges parallel to the shore and situated in water 1 to 10 meters deep are made up of a single species of Pocillopora...Great fingers of coral which rise from depths at least as great as our deepest dives (25 meters) were built by a horizontally frondose form of Porites which now lives around the outer edge of the 10 fathom terrace" (ocean side of atoll).

Lagoon reefs and islets

As shown on charts, and more accurately on air photos, the lagoon is crossed by a number of large reefs, the most conspicuous of which is a flat triangular one, located near the Rock and called Grand Récif. At times it is apparently emerged and it was probably part of it that Belcher saw and marked on his sketch as a round reef in the middle of the lagoon. Hennig's soundings give depths of only a few (3-6) inches (7-15 cm) of water over this reef. Snodgrass and Heller found nowhere less than 2 feet (60 cm) and at the time of our visit in 1958 Grand Récif was certainly more than just 7-15 cm below the surface although the divers occasionally scraped their knees against such reefs. The most conspicuous character of this reef is the presence in its center of an egg-shaped hole, Bottomless Pit (Puits sans Fond) where depths of 20 fathoms (36 m) have been reported (Arundel, ex Wharton, 1898). From its aspect on air photos, the Pit with its very abrupt change in photo density must have rather steep walls.

When traced from the air photos (see map) the reefs, including Grand Récif, have very dissected edges and are reminiscent of a karst surface. They may represent a karst now submerged but formed at the time when the reefs were emerged, during an epoch of lowered ocean level. A feature perhaps comparable to these reefs is the "Maze" of Pelsart Island described by Dakin (1919) and illustrated and interpreted by Fairbridge (1948 pp. 17, 28, and pl. III). In this case live organisms are growing on an older, eroded limestone platform. The suggested karst, in Clipperton lagoon, presents a curious feature in that there is a roughly concentric arrangement of the reefs. This would bear careful further investigation as possibly indicating more than one episode in the fluctuation of sea-level during the Pleistocene. It may, on the other hand, correspond to what Tayama (1952 pp. 255-256) calls "double ring atolls"; he discusses possible modes of origin of these but arrives at no firm conclusion.

Besides the reefs which may, at times, be partly emerged, there are in the lagoon a number of small rocky islets. The more important group is the line of 5 Egg Islands strung parallel to the northwest shore of the atoll, only a little distance off shore. Four of them are quite small, the fifth and largest is about opposite the north corner of the island.

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* Species now living on the outer reef (Hertlein and Allison 1960a, 1960b); see also note p. 73.

There are also some islets across Pincer Bay and across Thumb Cove. The latter were often under water at the time of our visit but birds stood on them nevertheless. All these islets consist of consolidated phosphatized coral material as do the adjacent rocky shores. The three small islets located close to the south side of the Rock, on the contrary, are formed of the same volcanic material as the Rock.

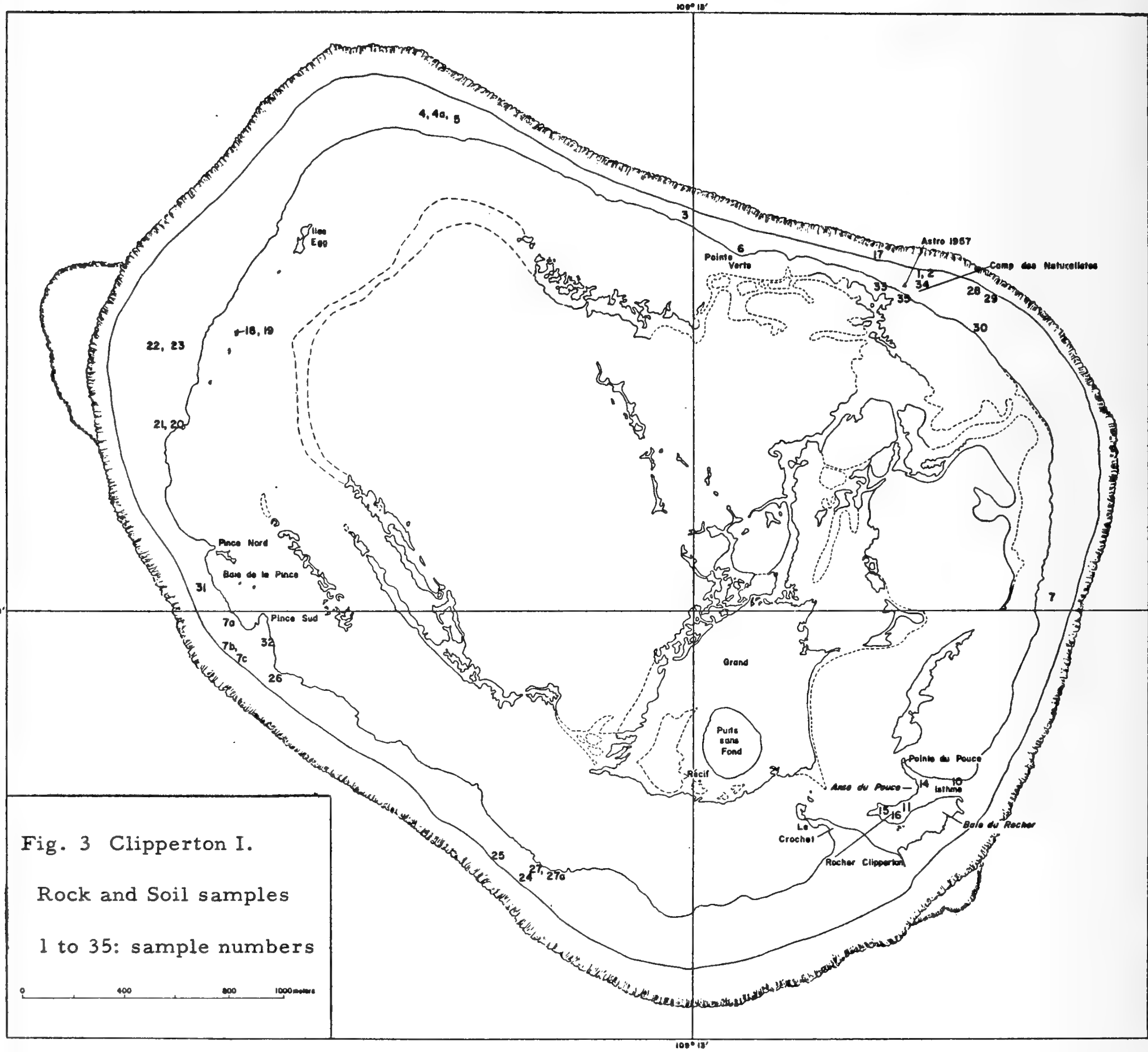

Fig. 3 Clipperton I.

Rock and Soil samples

1 to 35: sample numbers

LITHOLOGY

Except for Clipperton Rock, the rocks on Clipperton Island above the reef flat are almost entirely of organic origin and derived from the calcareous skeletons of animals and plants, and from guano deposited by sea birds. By far the more important original constituents are corals; mollusks, foraminifers and other animals, coralline and other algae, and pumice, are relatively minor constituents, much less important than in many other atolls such as the Marshalls. Phosphate has been added in substantial amounts. The sediments range in size from silt and fine sand to large boulders. Many are loose and almost fresh, some have been weathered into soil, some have been altered to phosphorite, and some are consolidated into various types of rocks, the inland ones mostly phosphorites, the beach rocks calcarenites.

Sufficient samples and detailed enough field observations to construct a reliable lithologic map were not collected. The locations of the samples are indicated by numbers on the map (fig. 3) and the distributions of rock types are roughly indicated in the descriptions of the land surface given above under Surface Features of Land Strip. Obermüller (1959) presents a geological map indicating the areal distribution and arrangement of loose calcareous materials and two grades of phosphate ores. In a few areas I collected unconsolidated materials where ores are indicated on his map. His discussions of phosphate ores deal only with consolicated types.

Only brief summaries are given of the occurrence of the groups into which my samples are arranged. More detail may be obtained by reference to the description of surface features and to Obermüller's map. The results of chemical analyses of my samples are given together at the end of this chapter, p. 66. Detailed petrographic studies have not been completed, and will not be included in this paper. Obermüller gives descriptions of some of his samples, analyses, and excellent photos of typical rock samples with photomicrographs of thin sections. His report may be consulted to supplement the present account, at least until studies of the samples are more advanced.

Reef sediments were not studied. Lagoon sediments were collected by E. C. Allison.

Loose sediments

The greater part of the island surface is covered by loose material, ranging in depth from very thin layers of sand or gravel partly covering consolidated formations to large masses several meters thick forming the boulder ridges. It was not practical to determine the thickness of the layers in most cases.

Sediments have been roughly arranged in size classes as follows:

Boulder and cobble gravel

Deposits of limestone debris of boulder or cobble size occur in various parts of the ocean side of the island forming high beach ridges (e.g. at the north corner) or boulder fields (southeast side). These deposits may be well sorted or with smaller gravel and sand filling the interstices. Most of the boulders are smaller than a child's head, and worn and rounded. Occasionally larger, more irregularly shaped boulders occur, either among the others or more often as storm-cast isolated blocks. One such block observed on the northeast gravel sheet measured90 cm along its base and was 75 cm high. It was a chunk of coral, veneered with a layer of shells of vermitid snails. Other blocks of similar sizes have been cast up far inland. Large blocks and rounded boulders are pieces of massive coral colonies, and appear to represent a very small number of species. No sample of this rock type was collected.

Gravel

A very important sediment on Clipperton Island is a type of gravel made up almost entirely of branched coral pieces, probably one or several species of Pocillopora. Some of the fragments are perhaps large to be classed as pebbles, but the majority fit better in this size class than with cobbles. Such gravel forms a great part of the beach ridges around the island, as on the northwest side, outside the southwest coconut grove, and in the south, between Rock Bay and the reef. Some of these ridges, as described above (p. 38), extend for some distance inland in wide gravel sheets especially on the northeast side, at the north corner and on the Rock Bay side of the Isthmus. The gravel in these sheets was probably spread over the land at the time of storms, and occasionally was poured as far as the lagoon edge, where it forms gravel bars (see p. 42). The following samples were secured:

Sample 7c:

Consists of pebbles 4 to 7 or 7.5 cm long and up to 3 or 5 cm wide, rather well sorted and mostly white in color. The pebbles are mostly somewhat branched pieces of apparently unaltered coral, most of them rather worn and rounded but some quite fresh, or rounded fragments overgrown with other organisms such as snails or algae. The sample is perhaps too small to be quite representative, as it should include larger fragments. It was collected on the ocean side of a beach ridge, opposite the southwest coconut grove.

Sample 4:

Pebbles 3 or 5 to 7 or 7.5 cm long, varying in width up to 4 cm, stained gray (gray-black when fresh) by microscopic algae. The pieces are branched fragments of coral, somewhat worn, but with very sharp edges and angles. While in size they compare well with sample 7c, their sharp cutting edges are in great contrast with the rounded outlines of the pebbles

of that sample. The gravel represented by sample 4 was strewn over the ground in a thin interrupted layer, often only one pebble thick, at the north corner of the atoll. Underneath was a consolidated pavement (cf. sample 4a) or a fine soil.

Sample 25:

Gravel very similar to that in sample 4, but with pieces 6 to 13 cm long and 3 to 6 cm wide or more. The coral fragments are much branched, with sharp edges, and stained dark gray or almost black with an encrustation of microscopic algae. When knocked with a hammer or against one another, such pieces gave a somewhat ringing sound. The coral is partly altered and easily breakable, or in places friable. This type of gravel, made up of large branches, is extremely unpleasant to walk on. The sample came from the landward side of the gravel ridge in the southwest part of the island.

Fine gravels, sand, silts and mixtures of these:

The majority of sediments on Clipperton are of these size classes, but, except for beach sand, they are rarely well sorted, and occur most often in mixtures of materials of several different sizes. Much of the vegetated part of the island is occupied by such mixtures. Most of these sediments, except the beach sands and those making up the surface layers of the washes, are highly phosphatic and have some accumulation of organic matter showing some differenciation to soils. Soils as such are discussed below (p. 75).

Sample 19:

Poorly sorted mixture of fine gravel of altered coral, and phosphatic crust fragments up to 2 or 3 cm greatest diameter, mostly rather thin, with a small amount of coarse sand made up of the same material. Light brownish gray, mottled with paler. Some pebbles stained with algae. A few dead shells and shell fragments, fish bones, and feathers. From a depression in the consolidated rock (sample 18) forming one of the small Egg Islands.

Sample 34:

Unsorted mixture of small pebbles of coral up to 3 cm greatest diameter, somewhat altered but still resistant to crushing, and pieces of phosphatic coral conglomerate, fine to coarse sand and small amount of silt. Gray-brown color mottled with paler to white when dry. Fine fractions (34a) highly phosphatic, coarse (34b) less so. Sample completely loose in structure. Occasional dried undecomposed leaves, occasional sub-fossil land shells.

This material formed the surface deposit in the vicinity of Naturalists' Camp, and where collected, between the camp and the lagoon, was at

least 20 cm deep. Nearby, it was buried under a layer of sand locally 8-10 cm thick but of varying thickness.

Sample 36:

Mixture of small, partially altered, coral fragments and what appears to be fragments of phosphate cement, gray to grayish white in color. Highly phosphatic.

The material is a sample of commercial phosphate from Clipperton, received from the Pacific Chemical and Fertilizer Company in Honolulu through the courtesy of Mr. Ronald Q. Smith. This sample is included here with some doubt, as it is recognized that it is perhaps not in its original condition but may have been derived, at least in part, from a conglomerate by crushing.

Sample 7B:

Fairly well sorted fine lime sand, almost white but with scattering of brown particles, completely loose in structure. When boiled in a cobalt nitrate solution (Meigen's reagent) which stains aragonite purple while calcite remains white, this sand becomes almost entirely purple, with only a very small fraction of white grains. Generally corals have skeletons of aragonite, molluscs have shells of varying proportions of aragonite and calcite, depending on the species, red coralline algae, echinoderms and foraminifers have skeletons or tests of calcite. Sample 7B is from the beach on the southwest coast, opposite the coconut grove.

Sample 1:

Medium to fine lime sand with occasional coarse particles and shell fragments, finer material partly coral debris but with material of many other origins, the whole pale brownish gray but slightly stained with greenish, pale green when fresh, entirely loose in structure except for occasional fragments several mm in diameter of fine material bound by algae which probably formed a thin crust on the surface. Layer 0.5 to 1 cm thick lying on top of sand represented by Sample 2.

Sample 2:

This is essentially similar except for possibly a slightly larger proportion of coarse to medium grains and a pinkish cream color with no trace of green and no fragments of algal crust. Most of the grains are stained purple by Meigen's reagent, but the proportion of white grains is greater than in sample 7B. From top of storm beach, opposite Naturalists' Camp, on northeast side.

Sample 7A:

Unsorted mixture of altered coral fragments up to 2.5 cm long, with small amount of coarse to fine sand and a considerable proportion of silt, either loose or coherent in small friable granules up to the size of coarse sand, with admixture of dried roots and grass, frequent small land shells. The whole a brown gray color somewhat mottled with pale. Forming surface layer in southwest coconut grove, between clumps of palms.

Sample 14-1:

Mixture of small fragments, from coarse sand size up to 1 cm in diameter, of very much altered friable coral, and silt mostly aggregated into firm but friable crumbs up to coarse sand size, a few small root fragments. Gray brown mottled with whitish when dry, light brown when fresh, forming a layer 10-15 cm thick lying on Sample 14-2.

Sample 14-2:

Coarse irregular coral fragments up to 5 cm or more in length, outer layers (14-2a) dull gray-brown, and altered to phosphate, inner part (14-2b) preserving structure of coral, whitish, friable; interstices filled with fine to coarse sand with some silt particles, apparently made up of the same material, light gray brown. Samples 14-1 and 14-2 from Isthmus, at the base of Thumb Point.

Sample 11-1:

Dark brown highly humic silt, with numerous fragments of leaves, crustacean shells, bird bones, small pieces of decomposed coral, roots, decomposed wood and other miscellaneous organic remains, somewhat sticky when fresh, caked and cloddy but friable when dry. Forming a layer 8-10 cm thick. Many earthworms. Abruptly overlying Sample 11-2.

Sample 11-2:

Mixture of highly altered coral fragments up to several cm long (11-2b), a fine to coarse sand and much silt coherent into firm but friable sand-size particles (11-2a). Medium to light brown in color; outer layer of coral fragments yellow to ochre color, and friable; inner part white, less friable, preserving the structure of the coral. Considerable admixture of roots and small fragments of decomposed wood and other organic matter. Forming layer at least 10 cm thick, coral fragments becoming more abundant and paler downward. Samples 11-1 and 11-2 collected under coconut palms, at the base of the East face of Clipperton Rock.

Sample 21:

Grayish-brown silt, partially aggregated into crumb-like particles, friable when dry, mixed with a considerable proportion of whitish chalky particles up to 1 cm in diameter, ranging from quite friable to so hard that although they can easily be broken, they will not crush between the fingers. Fine roots fairly numerous. Many of the chalky particles appear to be pieces of phosphatic cement. Greatly resembles sample 22, but has even higher phosphate content and much more numerous chalky particles. Forming surface layer in bottom of long shallow trench near west corner of island. Material was apparently dug out of this trench and piled up into some mounds nearby, from one of which sample 20 was collected.

Sample 20:

Resembles sample 21, paler color, greater proportion of chalky fragments, some of which still show coral structure. Both samples are highly phosphatic.

Sample 22:

Uniform brownish gray (pale chocolate color when fresh) silt aggregated into crumb-like particles which are friable under some pressure when dry, with a few paler fragments of chalky friable material, occasional roots. Forming a surface layer 8-15 cm thick overlying Sample 23.

Sample 23:

A layer of irregular aggregates of pale gray firm but friable chalky material of silky texture when crushed, embedded in finer grades of apparently the same material. On close examination this material presents the appearance of a semi-consolidated coral sand which has undergone a chalky alteration. Analysis shows that it is highly phosphatic. These two samples came from a wide area of fine soil in the oceanside half of the northwest land strip.

Sample 31:

Broken up material of the same sort as sample 23. From a mound at the north end of the southwest coconut grove, perhaps a pile of phosphate ready for shipment.

Sample 15:

Dark brown loamy material, partially aggregated into friable clods, mixed with highly altered coral pebbles up to 2 or rarely 3 cm in diameter. Various fragments of plant tissues, bones, egg shells, feathers, etc. Forming surface layer in passageways within Clipperton Rock.

Sample 32:

Dark brown partially decomposed litter, made up chiefly of fragments of coconut leaves, roots and other parts, mixed with more or less altered coral fragments and what appears to be fragments of phosphate cement, some of the coral pieces up to 3-4 cm long, most very small. Forming thick layer on the surface of the ground within the dense coconut grove on the southwest side.

Sample 3:

Pale creamy gray silt, powdery but some loosely aggregated into friable particles up to a cm across, mixed with a very small amount of fine to coarse sand and scattered rounded coral pebbles, these highly altered and chalky in appearance and somewhat friable under strong pressure. Forming a patch among the coral pieces of the northeast gravel sheet, and probably extending under it and representing part of the former surface layer.

Sample 5:

Fine light grayish-brown silt, somewhat aggregated into crumb-like friable particles up to 5 or rarely more mm in diameter, mostly less than 3 mm, in which are embedded a considerable proportion of worn coral pebbles up to 3-4 cm greatest diameter, these apparently not highly altered. Very few sand-size particles. Surface layer on emerged land strip, near north corner of island.

Sample 6:

A silt, dark brown mottled with pale brown and with a thin surface layer of a very pale gray, with a slight admixture of sand-size particles, small land shells and occasional small angular rock fragments. This material is plastic when wet and smelled slightly of H_2S when fresh. When dry it is from pale gray to gray-brown, friable. It is highly phosphatic. From mud flat occasionally inundated by lagoon water, and lined with a bed of sedges, on north end of northeast side.

While several piles of material which may represent stock ready for shipment consist, in part at least, of fine highly phosphatic material (cf. samples 20, 31) it has generally been implied that the commercial phosphate was obtained from conglomerates. This may be borne out by the small sample of exported material, no. 36. In any case, the occurrence on Clipperton of finely divided phosphatic sediments, including large amounts of silt, has never before been unequivocally reported.

Arundel, in his unpublished journal (cf. p. 20), speaks of a sample from Clipperton which, if dried down to 10% moisture, "would then be like flour and very difficult to ship." Later, in discussing his own explorations and sampling, he repeatedly mentions "alluvials," brown in color or sometimes lighter, which apparently are unconsolidated phosphatic materials but which, however, he nowhere describes.

Consolidated sediments

Except for the reef rock of the intertidal reef-flat, which was not studied, the consolidated sediments belong to two main types: beach conglomerate and phosphatic conglomerate.

Beach conglomerates

Sample 17:

Rounded small coral gravel, pieces mostly 1-2 cm in greatest diameter, some larger, some smaller, in a matrix of medium to coarse lime sand and shell fragments, firmly indurated at the surface, becoming less so downward, so that at a depth of 2-3 cm they can be somewhat crumbled between the fingers. General color pale pink, surface 5-10 mm stained green by algae. From one of the slabs of beach rock on the northeast ocean coast (see p. 36).

Sample 28:

Loose slabs, similar in nature to sample 17, but some with finer texture, harder, much more compact, well indurated, somewhat polished by wave action. General color pinkish white, upper surface slightly greenish, stained with algae but much less so than in similar material in place. Collected on the emerged land strip on the northeast side, where they were evidently thrown up by a storm as they were lying over the Ipomoea vines.

Sample 29:

Semi-indurated medium to coarse sand, the surface rather even and hardest, but easily broken with the fingers. Bonded by what appears to be a coarse silt. Induration extending downward to 2 or 2.5 cm, but becoming less firm. General color creamy pink. The surface stained greenish-gray by algae to a depth of as much as 5 mm, this also true of the vertical surface of the free edge of this material. Embedded coral pebbles common. Lying on loose material that is essentially similar to the indurated part but with perhaps less fine components. This may not be beach rock in the strict sense since it is only semi-indurated and lies above high tide level. Collected at the top of the sandy storm beach, opposite the camp on the northeast side.

Phosphatic conglomerates

The mode of occurrence of consolidated rock over major areas of the land strip has been described in the chapter on Surface Features of Land Strip, pp. 35-50. The original distribution and extent of these conglomerates, as well as that of the phosphatic silts and gravels which sometimes

cover them or replace them on the surface of the island cannot be known, because phosphatic material was removed from the island over a period of about 20 years.

As mentioned above, the commercial phosphate is generally believed to have been derived from consolidated rocks. Snodgrass and Heller (1902) say that "where good formations are found the mixture is dug up, broken into small pieces, dried, sacked and shipped without further preparation." Snodgrass collected some samples but they have not been described or analysed. Elschner (1913) published an analysis (see p 67) of a sample by Gilbert, which is reproduced by Lacroix (1939). Elschner writes that the material which he saw in a plant in Honolulu was in part a white, chalk-like material, in part a coarse yellowish gray powder, together with rather hard stones. The phosphatic conglomerate in its natural condition has not been described in detail until recently, when Mr. A. G. Obermüller published a report (1959) on his survey. I failed to find some of the types of conglomerate which he describes and conversely, I have not been able, in all cases, to refer my samples with confidence to his classes, although he has kindly given me portions of his samples. My collection contains some types of conglomerate which he did not obtain. This is easily understood, since neither of us spent enough time on the island for an adequate study, and our purposes were very different. Our collections overlap and complete each other. In the following descriptions of my samples, they are related, where possible, to the types described by Obermüller.

He recognizes 3 main types of phosphatic conglomerates: cuirasse, carapace and coral aggregates, but indicates that intermediate types occur and that the 3 types are stages in the consolidation and enrichment in phosphate of the coral material, the aggregates being the early stage and the cuirasse the latest and richest in phosphate.

<u>Aggregates</u> consist of pieces of coral, slightly phosphatic and cemented, where they touch, by a phosphatic substance. <u>Carapace</u> is a more compact rock, cream or brownish white, with a more or less compact phosphatic cement, often friable; spaces usually remain between the cemented coral pieces. In the <u>cuirasse</u> phosphatization is more advanced, the conglomerate is more compact. When in place, it is usually still somewhat vesicular, but spaces between coral pieces and cement are small. Samples taken by Obermüller from piles of phosphate stock are the most massive and include a type (AO-15-Cl.57) which is practically pure calcium phosphate without any remnant of coral pieces. In other samples (cf. AO-14-Cl.57), comparable material occurs between remnants of corals (at least between cavities with marks of coral pores) and together with a banded phosphatic material of a different texture. Comparison of samples 14 and 15 seems to indicate that what Obermüller interprets as possible traces of rootlets in sample 15 are rather the last narrow traces of the original vesicular structure remaining after spaces have been filled in by cement. These two samples of Obermüller's are two types of rock which I failed to find in my collecting.

Of the types which I did not see in his collection, the most striking is that represented by my samples 27A and 18. In this material, cementation of coral pieces by a hard, porcelain-like, banded phosphatic material

has apparently been followed by the solution of the coral pieces, and only casts of their pores seem to remain on the surfaces of the phosphatic walls. Such rock is heavy, but not compact, and looks more like a hard sponge than anything else. Samples 27A and 18 were collected not far above lagoon level, and solution may have been effected by lagoon water. Other samples approaching these and with remnants of pieces of coral still present and "rattling" within the spaces between the walls (cf. sample 4a) were collected or observed on top of the land strip. In this case, of course, superficial solution may be due to rain water.

This type of rock is very striking, but not abundantly distributed over the island. I have not seen any description of a comparable material in the literature on coral atoll or Pacific Island phosphates.

Sample 4a:

Formed of small coral pebbles in a rather abundant porous cement, probably phosphatic; the top surface seems to consist only of this cement, remaining to form the partitions of a shallowly alveolar surface and bearing casts of the coral pores. The color is from gray to black, stained by microscopic plants. On the underside, the sample is white to pale brown. Several fragments of coral can still be seen embedded in the cement. A broken one has a crystalline structure in the center while its outer surface has been in part dissolved so that the coral piece rattles and could probably be removed from its mold of cement. This sample cannot be very well fitted in Obermüller's categories, but is probably an aspect of the carapace type. It came from an area mapped as carapace. It was too small to be analyzed.

The rock represented by sample 4a is a type of consolidated pavement, rather thin and overlying a silty material (sample 5); sample 4a is 2-5 cm thick and was part of a rather extensive area of such pavement, in places overlaid by gravel (sample 4) or sand, at the north corner of the island.

Sample 10:

A conglomerate of coral branches of varying size embedded in a cement which is filled with sand and fine coral fragments partially dissolved away. The coral branches have become friable. The top surface of the sample is very uneven and rough and is stained from pale brown to greenish and black by microscopic algae. It is deeply alveolar, some of the holes representing molds of coral pieces which have been dissolved, or partly so, and loosened, leaving the hard phosphatic cement. The broken under surface is white or yellowish, very porous, showing the inner structure of the broken coral fragments. The lower part is probably nearest a carapace or intermediate between it and cuirasse, but the upper, alveolar part is of the type not described by Obermüller. The phosphate content (%P_2O_5) is more comparable to those given for cuirasse than carapace. The sample comes from an overhang of consolidated rock above the lagoon water, in the area just east of Thumb Point along the Isthmus.

Sample 27A:

This is a deeply vesicular rock, formed of walls generally 1-2 mm thick, locally more. These walls are very clearly marked with casts of coral pores and the whole rock may be what remains of a coral conglomerate from which all of the coral pieces have been dissolved, leaving the cement. The shape of the holes indicates that the coral fragments were rather large, many of them branched; some casts of branches are 4-7 cm long. Such fragments then must have compared in size with the loose coral material which forms much of the gravel ridges (cf. samples 4, 7c, 25). The whole rock is of a pale reddish brown, in places stained by algae. The sections of the walls are of a pale brown, somewhat banded or layered, very compact and fine textured, almost porcelain-like. Analysis shows this cement to be almost pure calcium phosphate. This rock does not fit the classes described by Obermüller. The sample was collected in the same general area as sample 27, but near the lagoon ledge.

Sample 18:

Very similar to sample 27A: Coral branches which had been cemented in a conglomerate have been almost entirely dissolved and the deeply vesicular mass of fine hard brown cement remains, showing the hollow casts of the corals. The marks of the coral pores are visible along some of the casts. In a few places the coral structure is still visible, but the fragments are apparently phosphatized. This rock had the highest phosphate content of all samples analyzed. The walls of cement have the same banded appearance and porcelain-like section of those in sample 27A but may in places be thicker. The principal difference between this sample and 27A is the fact that the upper surface is glazed with a thin, white shiny deposit very likely derived from fresh guano and perhaps polished by birds' feet. A similar glaze occurs on the surface of Obermüller's sample 28 (from the Isthmus), and a comparable one, but made up of aluminum phosphate (Lacroix p. 301) is common on the Rock. Sample 18 was knocked off the top of one of the Egg Islands, which was covered by nesting boobies and noddies with a few sooty terns. There was no vegetation on this or any of the other 4 Egg Islands.

Sample 27:

A dense conglomerate of small, worn coral pebbles embedded in an abundant sandy cement. As in sample 4a which it resembles somewhat, except for differences in the size and shape of the coral pieces, the top surface is alveolar, the coral pebbles having been dissolved out leaving the cement to form the low walls of the alveolae with casts of the coral pores. This alveolar surface is light gray to greenish, probably stained by microscopic plants, and is only about 2 cm thick; the walls of cement are very thin at the very surface, thicker (2-3 mm) below; under the surface material, the rock is compact, with white pieces of coral embedded in a coarse, somewhat friable, creamy cement. Analysis shows that the coral pebbles (27-1) are slightly phosphatized, while the cement (27-2) is highly phosphatic. The material should probably be considered as intermediate between carapace and cuirasse, because the lower part is quite

comparable to samples of carapace, but the upper part, except for the alveolar surface structure, is similar to some aspects of cuirasse. This sample is rather typical of much of the areas of ledges and pavements. It came from the southwest side of the atoll, in an area where several series of rock ledges are aligned parallel to the rocky lagoon shore. Sample 27 is from the group of ledges nearest to the lagoon.

Sample 24:

The pieces of conglomerate in this sample are rather light and friable. They consist of coral fragments of varying size embedded in a coarse cement containing coral grains. The coral pieces are rounded cobbles 8 cm or more along their greatest dimension, and pebbles. Pebbles and cobbles are white and some are so softened that they can be deeply scratched with a finger nail. The outer surface of the conglomerate is dark gray and in places covered with a thin crust, pale gray-bluish in color, and perhaps formed by microscopic plants. The cement and coral grains in it are white or pale yellowish. Except in a few small places of its roughly alveolar upper surface, this rock lacks the hard porcelain-like cement walls of samples 10, 27 and especially 18 or 27A. Analysis shows a lower phosphate content than in these samples. Sample 24 should probably be classed with the carapace, but it tends downward toward the coral aggregate category. This conglomerate forms a series of low steps separated by rather wide areas of flat pavement, farther inland than the ledges from which sample 27 was collected but in the same general area of the atoll.

Sample 35:

The upper surface of this conglomerate is stained green or brown by a dried crust of blue green algae (Lyngbya). The broken sides show white or yellowish pieces of coral embedded in a coarse, darker cement. The alteration of the coral branches varies. Some of them, freshly broken, are still crystalline inside, with a dull white layer 1-3 mm thick all around. Others are dull throughout and at times very friable. Some of the pieces collected are formed only of cemented large branches of coral, but in others a very small gravel, with grains of various sizes embedded in the same yellowish cement, fills the interstices between the branches. In places the coral grains seem to have been partly dissolved and the cement remains as the paper-thin walls of a miniature alveolar structure in formation, similar to that seen in sample 27 and others. Some rather fresh-looking coarse sand grains may have been deposited in the interstices between the coral branches after cementation. The rock is phosphatic but less so than previously described samples. It fits between carapace and coral aggregates, parts of the sample being nearer the one or the other. It was collected underwater, at the edge of the lagoon, a little north of Naturalists' Camp. There the coral conglomerate forms low banks above the lagoon and extends under water.

Sample 33:

Several pieces of a poorly consolidated coral rock. White, rolled, worn pebbles of coral, 1.5 to 5 cm long are covered over part of their surface by a yellowish crust which holds them together where their corners or edges touch, leaving empty spaces between the pebbles. Occasionally the cement is more abundant and the empty space much reduced, or the spaces may be partly filled with a pale milk-chocolate colored fine sand, probably phosphatic. In some of the pieces in the sample, a beginning of the formation of an alveolar surface can be seen: some of the coral pebbles are superficially dissolved and loosened from the thin walls of cement. Except for this aspect, the sample is typical of the coral aggregate type of Obermüller's. Analysis shows that the phosphate content of this sample is low.

This sample is from the lagoon shore cliff northwest of Naturalists' Camp (described above p. 41). The upper part of the cliff, 15-20 cm thick, is similar in structure to the ledges of other regions of the atoll, consisting in a conglomerate of coral fragments in a dense dark cement. This changes downward to a much thicker material of loosely cemented pebbles; in the upper part at least, the interstices are filled with fine sand. Sample 33 represents this part of the cliff. The more lightly cemented pebbles can be loosened from the cliff face by a moderate stroke of the hammer. The lagoon cliffs of the northeast side between Green Point and Naturalists' Camp form the edge of the area affected by the 1957-58 storm and covered with a layer of fresh coral gravel. The loosely cemented material represented by sample 33 was evidently exposed at the time of the storm by the breaking off of the harder, more compact cliff face. Detached blocks of a harder, darker rock were lying at the base of the cliff, and some jutting pillars, not recently broken, had the same appearance. Parts of these pillars, as well as the upper part of the cliff top, consisted of a type of alveolar hard rock similar to that represented in sample 27A, i.e. with much or most of the coral dissolved away, leaving the dark reddish-brown hard phosphatic cement walls. On cliffs not affected by the recent storm, the exposed top surfaces and vertical faces consist of a dark conglomerate comparable to the more compact ledges.

Between the cliff damaged by the 1957-1958 storm and the lagoon shore stretched a bank of coral pebbles. Most of this material was probably thrown over the whole width of the land strip by the storm but some appeared to consist of pebbles detached from the newly exposed, poorly consolidated cliff face. Time was not available to study the material in the bank in detail to ascertain its origin.

Clipperton Rock

The volcanic material which forms Clipperton Rock is generally, on fresh surfaces, of a rather light gray, sometimes with bluish or reddish tinges. Unaltered rock has never been found, the dome being superficially altered to unknown depths, at least 30-60 cm, and phosphatized. Even the freshest-looking samples have shown some alteration.

Descriptions and analyses of this rock have been given by Agassiz (1894), Teall (1898), Lacroix (1939) and Obermüller (1959). The latter two authors include very detailed petrographic descriptions of samples with, in the case of Obermüller's report, fine photographs of samples and thin sections. Following his classification of lavas, Lacroix described the Clipperton material as a "rhyolitoïde à la limite d'un trachyte." Most authors call it a trachyte. My specimens have not yet been studied, and the detailed descriptions of Lacroix and Obermüller can be consulted. They include information on the progressive phosphatization of the rock.

From Obermüller's summary description (p. 54) the principal characteristics of the rock may be listed as follows:

--pseudo porphyritic texture
--abundance of sanidine
--xenomorphic character of quartz which is secondary and is probably pseudomorphous after tridymite
--existence of primary sodic pyroxenes as indicated by the occurrence, however sporadic, of unaltered aegirine-augite within an intact crystal of sanidine
--existence of fresh sodic amphibole molded on the sanidine microlites, and often associated with decomposition products of the pyroxenes
--probable absence of plagioclase as a component of the lava
--presence of fresh katophorite, xenomorphic and neogenetic in character.

This rock may be considered an alkaline trachyte; this is not essentially different from Lacroix' identification as a slightly more acid rhyolitoide, the slight difference being due probably to the fact that his samples were more altered than those collected in 1957.

The phosphatic solutions from the guano affect especially the superficial part of the rock, perhaps to a depth of one meter, leading to the phosphatization of the lava:

--either by formation of variscite in the leucocratic zones
--or by formation of strengite (or barrandite) in the melanocratic zones.

While I failed to find them, Obermüller reported the presence of minute fragments from the volcanic rock on the coral rim, and explained the rare occurrence, in the phosphatic coral conglomerate, of variscite, an aluminum phosphate, as being derived from them.

Sample 16:

Collected from the encrustations mentioned in this paper on p. 44. It appears to be a water-deposited material, perhaps comparable to that described by Lacroix as superficial encrustations representing aluminum and calcium phosphates of varying composition and relatively recent origin. Sample 16 is a piece of a large crust, in places loosened from the vertical volcanic wall on which it has been deposited. The sample is pale brown, 1-3 cm thick, the underside paler and powdery, the upper surface made up of small branched efflorescences.

Pumice and other extraneous materials

The occurrence of drift pumice and rafted rocks on atolls is well known, and takes on special significance in the ecology of these islands in view of the limited number of chemical elements otherwise present in an organic limestone environment. Examples of such occurrences have been listed by Sachet (1955) and by Emery (1955).

Pumice was found on Clipperton, although it occurred as relatively few scattered pieces, rather than as large fields or windrows as described on other islands. Most of the pumice was collected on the east side, which was visited more often because of the location of the camp, and where pumice was more easily located in the washes on the large expanses of sand. It may be equally common elsewhere on the atoll. Arundel, in his unpublished diary, describes an area at the base of the Hook that he sampled for phosphate, and where a layer of "alluvial" (phosphate) about 12 inches thick overlies a layer (?) of "Pumice or clay - very white". This is a rather puzzling reference, unless the pumice were extremely decomposed.

The pieces collected in 1958 range from pea-size fragments to cobbles of 15-20 cm greatest diameter. On superficial examination, they seem to represent several different types, as follows:

The large cobbles, as well as some smaller pieces, have a dense spongy structure, with visible criss-crossing fibers. They are discolored, but if the surface is scratched, the pumice appears pale gray, or almost white.

Most of the pea-size and some larger pieces are of very finely porous texture, rather than fibrous. They are white or gray and some include numerous crystals of both white and dark minerals. Several pieces consist of long shiny fibers, all arranged parallel to one another, the whole piece having a silky appearance. Fragments of these types were collected at the edge of the lagoon, and have been so altered that they can be crushed to a very fine powder between the fingers.

Several pieces of shiny black vesicular material may be slag from a ship's furnace rather than volcanic rock. A flat piece of dark, compact, heavy rock found not far from the camp is perhaps boiler scale. At the base of the Rock are large pieces of coal, possibly dating from phosphate mining days, or from a wreck.

Near the east corner of the island, in an area where much drift is present, and arranged along ocean-lagoon lines of flow, there are among other things planks and other pieces of wood, bottles, Japanese glass floats, small pieces of charcoal, and also some small flat pebbles with rounded edges of volcanic or possibly metamorphic rock. The pebbles may have come from ballast, or have been rafted by drift trees. A beautiful example of a rafted boulder was photographed near the north corner of the atoll by E. C. Allison. A large drift tree base holds a rounded piece of greenish volcanic rock.

Analyses of Clipperton Island Samples

Samples were analyzed by the Geochemistry and Petrology Branch, U. S. Geological Survey, by methods similar to those described in U. S. G. S. Bulletin 1036-C; Paul L. D. Elmore, Samuel D. Botts and Ivan H. Barlow, analysts.

Lab. No.	Field No.	% MgO	% CaO	% P_2O_5	% CO_2
154383	3	.46	50.4	14.6	25.3
154384	5	.28	48.5	27.4	10.9
154385	6	.77	44.6	30.4	5.2
154386	7A	.16	50.2	20.8	18.9
154387	10	.85	49.3	36.8	3.6
154388	11-1	.16	32.2	23.6	.48
154389	11-2a fine part of sample 11-2	.16	45.2	35.6	2.0
154390	11-2b coral fragments from sample 11-2	.20	50.4	24.8	16.4
154391	14-1	.54	46.0	34.7	2.6
154392	14-2a outer part of coral fragments	.32	49.8	37.1	2.8
154393	14-2b inner portion of coral fragments	.12	53.7	.60	41.7
154394	15	.13	53.0	1.1	40.9
154395	16	.17	30.0	29.0	.14
154396	18	.46	50.7	39.4	.30
154397	20	.18	49.5	37.0	1.7
154398	21	.10	47.5	36.1	1.0
154399	22	.19	46.1	34.6	.79
154400	23	.16	50.1	38.6	1.0

Lab. No.	Field No.	% MgO	% CaO	% P_2O_5	% CO_2
154401	24	.19	51.2	16.0	24.6
154402	26	.56	53.5	2.1	41.1
154403	27A	.62	50.0	38.8	.54
154404	31	.18	50.8	38.5	1.2
154405	33	.17	53.0	5.0	36.6
154406	34a fine fraction	.16	48.4	21.4	17.3
154407	34b coarse fraction	.06	52.9	6.3	35.6
154408	35	.28	53.1	10.0	32.0
154409	36	.44	50.8	31.2	9.3
154410	4	.14	53.0	.17	41.7
154411	27-1 coral fragments from conglomerate no. 27	.42	54.2	2.2	40.2
154412	27-2 cement from conglomerate no. 27	.28	50.9	28.9	11.5

Analysis of Clipperton Island Commercial Phosphate

(from Elschner 1913, p. 91, reproduced in Lacroix 1939, p. 303)

$3CaO\ P_2O_5$	78.09	NaCl	0.15
$3MgO\ P_2O_5$	0.55	SiO_2	0.28
$CaOCO_2$	6.73	Al_2O_3, Fe_2O_3	0.04
CaO	2.84	Organic matter	4.83
$CaPO_3$	0.78	Loss on ignition	3.80

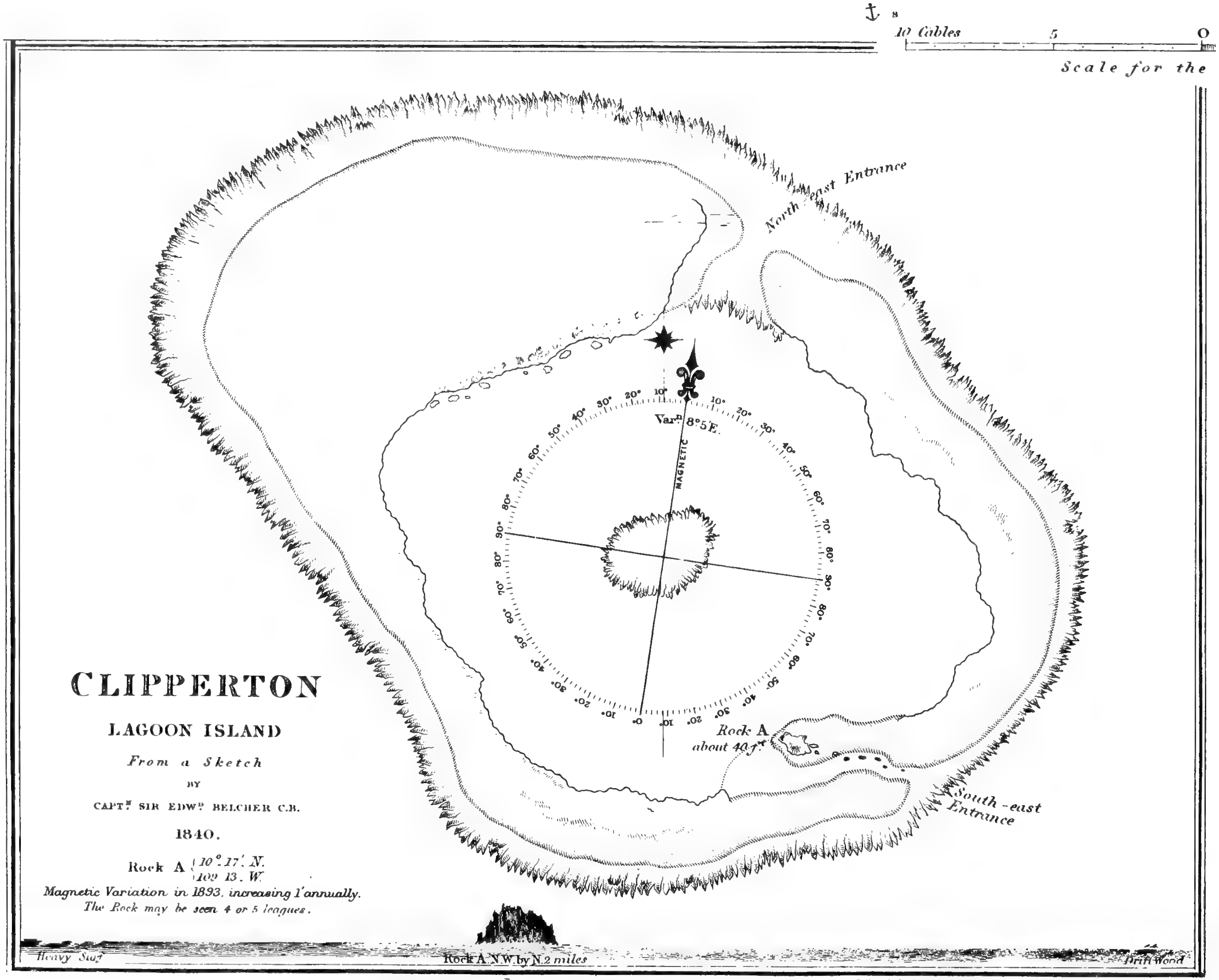

Fig. 4 (from Admiralty Chart No. 1936, 1893 ed.)

PHYSIOGRAPHIC CHANGES

Geological change

In terms of geological history, atoll islets may be regarded as ephemeral, or at least very changeable, features, even though their submarine foundations are in certain cases known to date back to the Eocene or even the late Cretaceous (Ladd 1960). On most of them are found some features which record or indicate some of the later changes that have taken place. The principal difficulty at present is to read and interpret this record. On Clipperton, features which may be significant in this respect are the "karst" topography of the lagoon bottom (described on p. 49), the step-like concentric ledges of consolidated rock (described on p. 40) and the two tiny remnants of an old consolidated surface persisting as undercut shelves or ledges on the side of the volcanic Rock at between one and two meters above low tide level (described on p. 44).

The karst-like lagoon bottom suggests one or more earlier periods of considerable emergence and subaerial erosion, a history which has, indeed, been suggested for coral islands generally (MacNeil 1954). Present inadequate knowledge of the details of this lagoon bottom precludes any more adequate discussion of this aspect.

Both the concentric ledges and the shelf remnants suggest a more recent period of somewhat greater submergence, or higher sea level. Detailed study of these, including careful levelling, might make possible a more adequate outline of the post-glacial history of the atoll and perhaps a correlation with similar features on other atolls, and coasts in general. The concentric ledges should be studied in the context both of the phosphatization of the coral and the possibility of changes in salinity and acidity, as well as in level, of the lagoon water.

The fact that the shelf on the small islet of volcanic rock slopes from a level of a meter or more at one end to about lagoon level at the other can scarcely be explained on the assumption of changed sea levels only. Without careful excavation, the only suggestion that seems tenable is that the rock fragment may be a loose one, lying on coral gravel which could have been washed out, somewhat, during a storm, permitting the slumping of one end of the rock.

Historical change due to natural causes

Historic data show that the island has undergone changes in certain of its features. The most important one is the closing of the reef openings and the consequent freshening of the lagoon. Unfortunately, neither of the earliest accounts of Clipperton Island remark on the condition of the atoll ring or the lagoon in 1711 (France 1912) or 1825 (Morrell, 1832). The map furnished by De Prudhomme does not show any opening, but is such a sketchy draft that no absolute reliance can be placed on it. Morrell landed on Clipperton, and it is tantalizing that he should not say more than he does. He makes no mention of openings or lack of them, or of the taste of lagoon water.

Clipperton was first seriously mapped by Sir Edward Belcher in 1839 (Belcher 1843) and two openings were seen from the masthead (fig. 4). In November 1858, Le Coat de Kerveguen found the coral ring continuous (France 1912) and, as far as known, it has remained so ever since, although ocean waters pour over the land strip and into the lagoon with some frequency. Belcher is the only author to have seen the openings if we except a not too reliable report by Permien (Anon. 1897-98, Aug. 19) who wrote: "There was, at the time I first saw it [in May 1881], a channel connecting the lagoon with the ocean, but on my later visits [1892] I found that this had been choked by logs and drift. The lagoon is now a body of fresh water not connected with the sea, and the pearl oysters in it have died." The validity of Belcher's observations cannot be doubted. The nature of the openings, and the manner of their closing may be discussed, however. At present the areas where the 1839 openings were located can easily be recognized. One is the great northeast sand wash, the other is across the land strip opposite the Isthmus. The absence of high consolidated rock, either as elevated beach rock, or island phosphate rock, is notable in both. In 1958, the great sand wash had a maximum elevation of 0.65 m above estimated mean high tide level, and while the southeast spot was covered by a gravel beach ridge topped in part by a recent small sand spill, it was not very high, and apparently was entirely made up of loose, removable material. Griswold (Pease 1868) described this area as "a heap of fragments, piled in windrows by the waves" and some photos taken in 1897 show it as a composite gravel ridge. It is quite easy to imagine that a storm, or several storms, could have closed the openings by piling up sand or coral gravel across them. However, the outer reef of Clipperton does not show any important interruption near the former openings. It is narrower on the northeast side, and its surface may be somewhat depressed near the northeast landing place, but this is probably south of the former opening. My impression is that the 1839 openings were not boat passages, but only reef-surfaces temporarily cleared of accumulated material, and therefore extremely shallow, and perhaps quite short-lived. This interpretation is compatible with Belcher's description which says: "There are two entrances, which at high water may be safe; but at the moment we passed, the surf was too heavy, and the reflux showed the rocks bare." These rocks must be the surface of the reef, the bottom of the entrances. The storm or storms which closed the 1839 openings may well have changed the surface of the reef and, more especially, the reef front, in such a way as to facilitate the accumulation of material so the openings have never formed again. This interpretation might seem to disregard the fact that the lagoon, with coral heads and other marine animals in position of growth, has obviously for long periods of time, been in communication with the ocean. My impression is that the closing and freshening of the lagoon had started before the disappearance of the 1839 openings, and that the period when it was in ample communication with the surrounding ocean was probably much earlier, perhaps dating back to a time of higher sea-level. A detailed study of the topography of the present reef, and of the nature of the dead marine fauna of the lagoon, including the physical condition of the dead shells and corals, could help reconstruct their history. At the same time, the lagoon reefs should be investigated (see p. 49, note p.73).

Another instance of historical change in the Clipperton land strip is that observed on the northeast side, and attributed to a storm occurring

between November 1957 and May 1958. On the air photos taken in September 1943, the area northwest of Naturalists' Camp and to the far side of Green Point exhibits fine lines parallel to the shore, similar to those marking the phosphatic ledges elsewhere. The vegetation cover appears irregular but continuous and probably consists of mixed herbs, with Ipomoea patches recognizable in some places. A sedge marsh occupies the tip of Green Point. Beyond Green Point, and as far as the area where the land strip begins to widen and curve to form the north corner of the atoll, no more lines are visible, there is much exposed sand and the vegetation appears to consist only of Ipomoea vines.

The photos taken from the helicopter in November 1957 do not cover all of this area but show very well the vegetation extending for several hundred meters northwestward of Naturalists' Camp with Ipomoea vines creeping down the beach and a small coconut palm near Green Point.

In August 1958 changes from these conditions were spectacular. Most of the northeast side of the atoll was denuded of vegetation and covered with fresh coral material. Going northwest from Naturalists' Camp and past Astro 1957, the ocean to lagoon cover of Ipomoea pes-caprae vines stopped abruptly 45 m from the Monument, and gave way to a sheet of coral gravel, in places at least, lying over coral sand or phosphatic silt. The gravel was rather evensized but mixed with occasional larger cobbles white, and somewhat imbricated from ocean to lagoon. Here and there large boulders had been tossed up onto the land strip. Some gravel had poured into the lagoon and was being reworked into low banks by the lagoon waves. Where the old land surface ended in a cliff at the lagoon edge, the cliff face in places had been undermined and broken up and the fresh gravel was mixed with material detached from the cliff (see p. 63). On the ocean side, the edge of the land surface was undercut and broken up forming a ledge, and coarse sand or gravel sloped down from it to the beach, except where a thick formation of conglomerate, also eroded and broken up at the top, formed the ocean slope (see p. 37).

Some sandy areas near the lagoon edge of the gravel sheet, elongate in an ocean-lagoon direction, seemed to mark channels along which the water drained off. Some were occupied by fresh plants of Cenchrus or Ipomoea pes-caprae. Otherwise the gravel sheet was bare of vegetation, and obliterated any earlier surface features of the area, such as ledges.

Somewhat beyond Green Point, the gravel sheet was interrupted, and the land strip formed an escarpment along the ocean-lagoon section, 1.40 m at its highest point, and with a slope of gravel below it. Beyond this bluff, northwestward of the gravel sheet, the land strip became very low (0.65 m above estimated mean high tide level) and sand stretched across it from ocean to lagoon forming the great sand wash and extending for 430 m toward the north corner of the atoll. At its far end, it gave way to a boulder field, and finally to an area covered with vegetation which appeared undisturbed.

The storm then has deposited coral debris over a strip several hundred meters long, and across it into the lagoon, at the same time undercutting and eroding the ocean shore. Drift seeds and pumice were collected on the lagoon beach, if proof were needed that ocean waves reached the lagoon.

Southeast of the most spectacularly affected area, opposite Naturalists' Camp, the storm had eroded and undercut the island rock, and deposited boulders and slabs of beach rock at the top of the beach, and even over the vegetation of the land strip. Some sand was spread over the Ipomoea vegetation and, washing down among the vines, covered the phosphatic silt. A buried soil was found, near the small group of palms, under 8-10 cm of sand.

The emplacement of a tide gauge installed near the wrecked LST in 1956 was demolished, most probably by the same storm, and the wreck itself was so battered that the mast and much of the stern fell in the ocean. These changes were observed, together with the conspicuous white coral strip on the northeast side, in May 1958 (W. L. Klawe written communication).

That the storm waves did not affect only the land and the upper parts of the underwater slopes is demonstrated by observations made by the marine biologists. Allison (personal communication) was able to observe some species of corals which grow only below the edge of the 10-fathom terrace; the large boulders made up of their skeletons and thrown up onto the reef and even the land strip had therefore been lifted from this depth, at least. This effect of the waves at considerable depth is confirmed by some observations of the divers along the undersea slopes. They observed great differences in aspect between the northeast slopes and those elsewhere around the atoll and believed that they were seeing storm effects as far down as 30 to 45 meters. Detailed descriptions of such observations, when available, will be of great interest indeed. Newell (1956, p. 344) also suggested that some of the coral debris thrown up by hurricanes on the reef and islets of Raroia Atoll originated on the terrace.

Elsewhere on Clipperton, along the southeast side, a vast area of sand may have been deposited, or at least reworked, by a storm, as suggested by the black coral boulders partly buried in fresh sand, and which must have been there for some time. The sand covers also the road marked in 1945. The surface of the sand is littered with great amounts of drift material, pieces of wood, dead coconuts, bottles, a very few glass floats, pumice, drift seeds, often arranged along ocean-lagoon lines of flow. Some white coral boulders were probably deposited at the same time. On the 1957 photos, this area is not very well shown, but it does not appear very different from what it was in 1958, so the fresh-looking material may have been deposited or re-arranged by a storm earlier than the 1957-1958 one.

In the southwest sand wash, black boulders partly buried in sand, also seem to indicate that the sand has been reworked, or added to. In this relatively small and rather permanent sandy area (see p. 35), the effect may be due mostly to wind, however.

Recent changes due to man

Some changes in the aspect of the island are due to man's activities. While most traces of phosphate collecting have been obliterated, some mounds of phosphate occur near the southwest coconut grove and the west

corner of the lagoon. Plants arranged in "lines" along the northwest side, may follow hidden trenches along which phosphate was dug (cf. p. 77). John Arundel (Anon. 1897-98, Aug. 20) wrote rather disdainfully of some early prospectors: "some one ... chipped off some big blocks of the [volcanic] rock under the hallucination that it was hardened guano, and hauled them two miles across the lagoon to the place where it was intended to ship the stuff. It lies there still. One might just as well use cobble-stones for a fertilizer as to use that rock." The chunks are still piled up on the lagoon shore, opposite the LST. Two sand mounds near the east corner may also date back to that period, as they were alread noticed in 1943. The phosphate workers in the 1890's had several houses and sheds on the northeast side, near the present Naturalists' Camp or somewhat northwest of it. Later, the camp was moved to the southwest side, and before 1945, ruins of huts and machinery could still be found. The trace of a ruined pier across the reef, opposite the southwest camp, can still be seen on air photos. Some shelters had also been erected near the Rock. In 1958 a low wall at the base of the east face of the Rock, some excavations and some large pieces of coal scattered nearby remained; the ruins of the phosphate digging establishments had disappeared, except for piles of phosphate, pieces of narrow-gauge rail track and a large iron mooring buoy; but the remnants of the U. S. Weather Station buildings were conspicuous on the southwest side, in the much-enlarged coconut grove. Roads had been built from the Station around the atoll, and can still be seen in most places, the vegetation having a different appearance and the plants growing lower on the compacted material. Photos taken in 1945 show a large cleared area where the Weather Station buildings were being put up, and a bank of coral on the ocean side of the camp, probably intended to protect it from storm waves. This bank is still recognizable today, although the coral has turned black and plants cover it in parts.

Another important change wrought by man of course is the introduction of animals and plants, which will be briefly discussed below.

Note: After the above was written, I received the following information. Dr. Carl Hubbs, in a letter dated Dec.27, 1961, says:" We have just received the radiocarbon date of 370 ± 100 years from the UCLA Radiocarbon Laboratory (their test No. UCLA-115) ... The test was made on a complete specimen (both valves) of a clam identified by Allison as Spondylus cf. pacificus, taken from a depth of 18.3 meters in the lagoon, in September 1958, by Limbaugh.

"The exact date, even within the indicated margin of error, is not to be trusted too implicitly, because there are expected fluctuations, and for other reasons." The date will be included in the 1962 Radiocarbon Supplement to the American Journal of Science.

This interesting result, in spite of the wide margin of error (marine carbonates offer serious problems in radiocarbon dating), in no way weakens the remarks made on p. 70, and confirms the view that within relatively recent times, the lagoon of Clipperton was sufficiently saline to support some strictly marine organisms. It also suggests that the present meager brackish water flora and fauna of the lagoon are of relatively recent origin.

GENERAL LAND ECOLOGY

Habitat

The outstanding ecological characteristics of Clipperton Island are the rigorous environment and paucity of habitats and land biota. The climatic conditions have been described above and can be summarized as follows: extreme insolation; moderate temperature, with little change throughout the year; high humidity; high rainfall probably with a dry period; variable but often strong winds; seasonal but frequent storms and hurricanes and incidence of storm waves.

The landscape as a whole is rather uniform and provides only a few habitat types: uniformly low altitude and little variation in topography, lack of much variation in chemical composition in the substratum, poor development of soils, little shade, all contribute to reduce the number of possible habitats, even more on Clipperton than on other atolls. For instance in the northern Marshalls, which are perhaps comparable in many respects, a greater variety of habitats results from the denser, more mature vegetation which includes several native trees providing shade, more differentiated soils, increased soil moisture locally, etc.

On Clipperton Island the surface soils are mostly very immature--coral sands and gravels only slightly discolored by organic matter. In some areas the surface material is phosphatic gravel derived apparently from the indurated phosphatic rock, but in many places the surface is of only slightly modified recently deposited material.

On the broad northwest corner are large areas of phosphatic silt with slight admixture of coral gravel, this especially scattered in a thin layer over the surface. The silt is differentiated into a brownish or brownish gray upper layer as much as 15 cm thick, lying on a pale creamy white layer, more compact, of undetermined thickness. The two layers are almost entirely calcium phosphate, but the percentages of both P_2O_5 and CaO are somewhat lower in the darker upper layer, perhaps indicating some profile development (cf. samples 22 and 23 p.56). Comparable material (cf. sample 3, p. 57) underlies the gravel sheet on the northeast side, at least in some places. Judging by the similarity of the material in old stockpiles on the west corner near the lagoon, this silt may be one of the kinds of phosphate that were mined commercially. Therefore its present extent is probably much more restricted than it must once have been.

Otherwise no significant profile development was observed in any well drained site except in the coconut groves where a thick surface horizon of partly decomposed litter and humus had accumulated on the coral (cf. sample 32, p. 57). Crab holes are abundant and doubtless there is a continual stirring up and turnover of the soil material, making any incipient horizons less distinct. Earthworms are locally abundant. Drainage seems generally excellent except on ground lying at about lagoon level. Here the soil, in its upper layer at least, is a dark highly organic silty mud (cf. sample 6 p.57).

The soil generally calcareous and phosphatic, may be locally enriched by small amounts of material from the volcanic rock and of drifted pumice and extraneous rock carried in drifted trees.

There is little visible evidence of the influence of soil on vegetation or the reverse, except in the soils of the coconut groves mentioned above, in the correlation of silty, highly organic mud with sedge beds in low places, and that of silty sand with Heliotropium and Conyza stands. Of course the continuing enrichment of the soil by guano and the past enrichment which led to phosphate formation undoubtedly make the soil a more fertile substratum for plants than the pure carbonate parent materials. Since this enrichment is a general feature, its effects are not revealed in the vegetation patterns. Recently deposited sands and gravels, not so enriched, have very little vegetation as yet but this is probably related to time and other factors rather than to lack of fertility.

Land Biota

The paucity of habitats on atolls in general and Clipperton in particular is matched by the poverty of the flora and fauna. In Pacific atolls, there is an obvious attenuation of the fauna and, more especially, the flora as one travels eastward, away from the land masses of Indo-Malaysia. This trend is complicated by the rainfall gradients. Despite the enrichment from the east, Clipperton Island's impoverished biotas fit well at the "end of the line."

Plant life

The flora and vegetation of Clipperton have been described in detail elsewhere (Sachet 1962) and only a summary need be given here.

While the present survey increased the number of plants recorded from Clipperton, only some fungi (mostly isolated from soil samples), lichens and blue-green algae, 3 mosses and 26 phanerogams could be found, with the addition of a few drift seedlings. All the species are listed below, pp. 89-94. There were several drift trees, or large branches, thrown upon the beaches or beach ridges.

Probably all the cryptogams present are of very wide distribution but too little is known of their general occurrence to draw useful information on phytogeography. The three mosses, at least, are pantropic. Of the phanerogams, some are pantropic and their place of origin cannot be determined (e.g. Ipomoea pes-caprae), a few are American (e.g. Heliotropium, Scirpus, Solanum). Only one drift seed, if its identification, Strongylodon sp., is correct, appears to be definitely of Indo-Pacific origin. Most of the land plants were probably introduced by man, a few deliberately (e.g. Cocos, Nicotiana, Brassica) others by accident (e.g. Waltheria, Corchorus, Solanum, Sida, Cenchrus, Eragrostis). The lagoon phanerogams and perhaps some algae (Proctor 1959), and the sedges may have been introduced from America by water birds.

There are no native trees or shrubs on the island. Except for the coconut palms introduced about 1897 and forming a few groups about the coral ring, the vegetation is uniformly low, only a few centimeters or in places a few decimeters tall, and made up of herbs, some of them suffrutescent.

The larger coconut grove on the southwest side, is too dense to allow any undergrowth or ground cover. No plants grow under the palms at the East face of the Rock either, possibly because of trampling by the pigs. The other groups of palms are so small that the surrounding vegetation simply extends to the palms or among them, without any perceptible change in character. Therefore, shade, humus, and the protection from wind, salt and evaporation provided by trees, are of little importance as factors influencing the vegetation. The slightly more luxuriant condition of some plants near the larger grove may just as well be due to the presence of the ruined camp and attendant disturbances of the soil, addition of chemical elements useful to plants, and other effects. Similarly, it is not known whether the taller, more luxuriant condition of Sida and Solanum around the base of the Rock is related to shade, disturbance of the soil, or addition of chemical elements from the volcanic rock or of organic matter from other sources.

The most extensive vegetation type on Clipperton is a herbaceous cover, a few centimeters to a few decimeters tall, made up of a varying mixture of grasses and suffrutescent perennials. The plants most commonly present are Cenchrus--a grass with spiny burs, Sida, Corchorus, and Solanum. Other plants occur, but less generally, mixed with these. Two plants appear to prefer sandy habitats and may form pure patches in such places; they are Heliotropium and Conyza. The mixed herbaceous vegetation is best developed on the northwest side of the island, which also appears to have been least disturbed in recent years. The density and composition vary and over large areas, some taller plants, densely growing together, form long narrow lines, roughly parallel to the shores. A thin layer of dark gray coral gravel covers most of the soil in this part of the atoll, hiding differences in soil, if any, along the lines of plants. Very likely, however, the lines indicate buried features; some may be the continuation of the phosphatic ledges found elsewhere around the atoll, and the majority probably are old trenches or furrows along which the phosphate was collected. One such trench is still clearly visible a little south of the west corner of the atoll, not far from the lagoon. On the 1943 air photos, it shows as a long dark gray strip, with four round spots along it. In 1958, the spots were found to be piles of phosphatic sand and gravel (cf. sample 20, p. 56), with a cover of taller vegetation, including much Brassica. Three piles are on the west side of the trench, the other on the lagoon side. The trench is 30 or 50 cm deep, several meters wide and at least 100 m long. The obvious impression is that the piled up material was dug out of the trench. This may be how the phosphate was mined. This interpretation appeared strengthened by some of Arundel's remarks in his diary (cf. p. 20). When he was on Clipperton in July-August 1897, he surveyed very minutely the phosphate resources of the island, and, in his notes on surveying and phosphate sampling, he often mentions trenches, apparently parallel to the shores, found mostly

in the northwest part of the land strip, the only area exploited at the time of his visit. His notes are too sketchy however to give an exact idea of the method of exploitation and to permit correlations with present observations.

The mixed herbaceous vegetation is also well developed on the southwest side and around the south corner of the land rim, but is generally lower. The former roads running from the old U. S. Weather station are marked by low, primarily grassy, vegetation. On some areas of phosphatic pavements, especially at the south corner, the mixed herbaceous vegetation consists mostly of clumps of Sida and Solanum, or large cushions of moss (Bryum sp.) with much bare ground exposed.

Another important vegetation type is a blanket of Ipomoea pes-caprae. The long thick vines, with their bright green leaves notched at the apex and purple morning glory flowers, cover the whole width of the land strip near the wrecked LST and Naturalists' Camp, blanketing abandoned boats and other equipment, and form thick masses of stems over lagoon cliffs or banks around most of the island, except in the south. Here and there these creepers extend into the mixed herbaceous vegetation, as on the west side where they cover the ruins of the weather station and on the northwest landstrip where they grow from old gnarled "trunks" several decimeters high. These have been interpreted as a sign of seasonal dryness, when the vines probably die back. I have found no reference to such thickened woody bases for this species, but somewhat similar, even larger, woody trunks of another species, Ipomoea tuba, have been observed on Pokak Atoll in the northern Marshalls (Fosberg 1955), where there is a very marked dry season.

Low muddy areas or small ponds and ditches along the lagoon shores are occupied by a vegetation made up of pure stands of several sedges. Tall, dark blue-green plants of Scirpus rubiginosus form a few small patches on the Hook and here and there along the east shore of the lagoon. They are rooted in mud, under water. In similar habitats, but much more abundant, occur the bright green dense stands of Eleocharis mutata, lining the shores with narrow strips or scallops and filling shallow ponds. The low pale green Eleocharis geniculata forms stands around the former, growing on wet mud, but not in water. Hemicarpha micrantha, the last species of sedge, prefers still drier habitats, and its small gray-green tufts are found outside the Eleocharis geniculata zone or alone in quite dry areas. The different requirements for wetness of substratum of the three last-named species sometimes lead to a striking concentric arrangement as at the base of the Hook in (E. mutata) and around (E. geniculata and Hemicarpha) a small pond. The dense stand of Eleocharis mutata in the pond is the habitat of the damsel fly Ischnura ramburii (det. C. F. Harbison). This same sedge and the Scirpus are used for nesting sites and material by the coots.

A type of vegetation which is not always recognized as such by the casual observer is represented by the crusts and films of blue-green algae which stain the sand green and blacken the coral around the atoll. Their role in the ecology of atolls is not known, although some possible effects of their occurrence have been suggested: the species

growing in sand may have a role in binding the sediments (Cloud 1952, p. 61; Doty 1957). Nothing is definitely known of the role of blue-green algae in nitrogen fixation on atolls, and yet it may be of great significance in view of the paucity of nitrogen sources in such environments. This has been suggested by Doty (1957) and Newhouse (1954, p. 53). In gypsum sand, a similar type of very sterile habitat, an increased amount of nitrogen in algae-bound crusts has been demonstrated by Shields and collaborators (1957).

Little is known of the ecological significance of soil fungi on atolls, but they doubtless play a considerable role in the decomposition of organic matter and a large flora of soil fungi is known from Clipperton (see p. 89 and Sachet, 1962).

Vegetation of the lagoon

In addition to various attached and floating algae, the vegetation of the lagoon is made up of aquatic phanerogams tolerant of salt. These plants, when alive, form great beds of weeds in the shallow parts of the lagoon, especially along the Isthmus and around the Rock, in Pincer Bay and around the Egg Islands. The most abundant is *Najas marina*, the stems of which, several meters long, are presumably rooted on the bottom. *Potamogeton pectinatus* was found around one of the Egg Islands, while *Ruppia maritima* is common attached to rocks just below the surface of the water together with filamentous algae. Great tangled masses of these plants float at the surface of the lagoon and are deposited on the shores in long rolls after periods of strong steady winds. On this plant material feed lagoon invertebrates especially the very abundant isopod, a species of *Cirolana*.

At least two plants are known to have been present in the lagoon, which could not be found in August 1958. One is the *Chara* collected in 1938 (W. R. Taylor 1939) the other is a phanerogam resembling *Zostera marina*, visible in great abundance on a photo taken in 1943 (Byrd 1943, vol. 4 photo 15). What caused the disappearance of these plants can only be guessed at. They may never have become really established but only have flourished for a brief period after their introduction. Or they may have suffered from changes in the salinity of the lagoon water, or other less obvious causes.

Animal life

Mammals:

In 1825 Morrell visited Clipperton and wrote (1832, p. 219) "Fur-seal and sea-elephant resort here in small numbers in the proper seasons ... After taking what few fur-seal could be found about the island ..." This is the only record of seals from Clipperton Island. Recent works (Allen 1942, p. 440, Scheffer 1958 p. 78) discuss Morrell's records of fur-seals on other islands of the East Pacific but make no mention of his Clipperton observations. However, Dr. Carl Hubbs (personal communication) believes there is no reason to distrust Morrell.

In the eastern Pacific, there are three fur seals, the Galapagos fur-seal (Arctocephalus australis galapagoensis Heller), the Philippi fur-seal of Juan Fernandez (A. philippi philippi (Peters)) and the Guadalupe or California fur-seal (A. philippi townsendi Merriam). All have been slaughtered ruthlessly for their skins and the Juan Fernandez seal may be extinct. The Guadalupe fur-seal was feared to be extinct or almost so when Dr. Hubbs (1956) found a small group of them on Guadalupe Island in 1954. Which of the three fur-seals could have occurred on Clipperton can only be conjectured, but the location of the atoll part-way between the home of the different fur-seals makes the problem especially intriging.

The northern elephant seal (Mirounga angustirostris (Gill)) now occurs only on some of the islands off the coasts of California and Baja California but formerly had a much larger range and could have reached Clipperton. With the disappearance of the seals, no native mammals remained on Clipperton.

Pigs were introduced to Clipperton Island around 1897, when a photo was taken showing two of them with the first two coconut palms, on the northeast side of the island. According to newspaper reports, these two pigs were survivors of the wreck of the British ship Kinkora (cf. p. 20). In 1917, when the phosphate works had been abandoned and the few remaining inhabitants were discovered and rescued by the U. S. gunboat Yorktown, about a dozen pigs were running wild on the island, the people being unable to catch and kill them (Morris, 1934). All visitors between that time and 1958 mentioned the pigs, most of them estimating their number as around 50, although the crew of the Ethel M. Sterling (cf. p. 7) reported nearly one hundred. In August 1958, all 58 of them were killed, because they seemed to molest the nesting birds. The pigs had lived in the Rock and hid in the larger clumps of plants near it, in the coconut grove, or in thick Ipomoea beds at the lagoon edge. They had worn white tracks on the dark coral gravel, or narrow paths in the vegetation. Their droppings showed that they ate plants and crabs, and probably also eggs and perhaps young birds. Some of the pigs were black, others a dirty pink, and spotted.

Unlike many other oceanic islands, Clipperton has been protected from the accidental introduction of rats and mice by the fact that ships cannot tie at the shore, but passengers and goods must be taken ashore by small boats. However, in August 1958, Mr. David Peterson (written communication) saw a mouse in a ruined quonset hut of the weather station.

Birds:

Most of the early visitors to Clipperton Island mention the great numbers of seabirds roosting or nesting there. Morrell in 1825 saw "the whole island ... literally covered with seabirds," and Belcher used almost the same words. Others mention myriads of birds. In 1958, even the most abundant species of birds occurred only in groups of perhaps a few hundred and it was obvious that there had been a serious decrease in numbers at some time. The common species were boobies, noddies and other terns, and frigate birds.

The brown boobies in 1958 were nesting and in addition to eggs, they had young of all ages. They were very abundant on the Rock, which they shared, almost exclusively, with white-capped noddies. They also occupied ledges and projections of consolidated phosphatic rock forming cliffs around the lagoon. Whenever a piece of such a cliff had fallen down, forming an isolated pinnacle in front of the cliff face, boobies could be found on it. Brown boobies also roosted in the coconut palms, and on the wrecked LST, with other species. The nests were of dry Ipomoea runners and grass, sometimes with a fresh green branch of Heliotropium, perhaps for decoration. Along the cliffs, the nests seemed more substantial than on the Rock, and were very clean because boobies can expell the guano a long way from the nest.

In November 1898 (Snodgrass and Heller 1902), they were common, breeding on the flat coral beach along the lagoon. In August 1905 (Gifford 1913), they were nesting abundantly all around the island.

The blue-faced or masked boobies in 1958 were much less abundant than the brown boobies. One with a red-orange beak had an egg on the northwest land strip. This part of the island, together with the Egg Islands, is where they were most abundant, but a few roosted elsewhere. These birds make no nest, only a slight depression in the ground. In November 1898 they were "breeding in immense numbers," in November 1901 Beck (1907) saw thousands of them, and in August 1905 a large colony was scattered among the brown boobies but not nesting. It may be that they are more numerous in the fall when they breed than during the summer months.

The absence of red-footed boobies from Clipperton was attributed by Snodgrass and Heller to the lack of bushes. In August 1958, Dr. Stager saw one on a palm near the Rock.

With the boobies, the most conspicuous birds on the island were the noddies. The common noddies occurred all around the island, sharing the rocky cliffs with the brown boobies and the Egg Islands with the blue-faced boobies and sooty terns. They also nested on all the abandoned rusting boats and vehicles on the island. Their crude nests included a few twigs of Ipomoea and sometimes a green Heliotropium branch. A few of them nested on the ground, with only a depression or a few pebbles and twigs marking the site among the Ipomoea vines. They had eggs, and the chicks started hatching during our stay. In 1898 they were very abundant on the Rock, and in 1905, on the Rock and the lagoon islets.

The white-capped noddies are not easy to distinguish from the others, unless they are seen together. The white-capped are somewhat smaller, the plumage is darker and the white cap in sharper contrast with it. In 1958, they nested all over the Rock in great numbers, on all the projections and in crevices too small for boobies. Some had nests of twigs and Heliotropium, others had no nest at all; some thick, guano-incrusted nests appeared to be old ones being re-used. Below the nesting places, trickles and splashes of guano covered the Rock. Some noddies were seen picking up Ipomoea vines, pulling on them or flying with them, the vines sometimes much longer than the bird. There may have been some confusion

with common noddies, here. The noddies in the Rock had eggs and, toward the end of our stay, chicks. The white-capped noddies nested also in the coconut palm near the Rock, where they badly damaged the fronds and especially young inflorescences by sitting on them and covering them with guano. There were noddies nesting also in the large southwest coconut grove. In November 1898, only immature birds were recognized, associated with the common noddies. In 1905 white-capped noddies nested in great numbers on the Rock, with nests of algae (or more likely lagoon phanerogams).

The sooty terns, or wide awakes, roosted in small numbers in the southeast part of the landstrip, opposite the Rock, and on the Egg Islands. A larger colony moved a little distance west from the north corner, to just landward of the beach ridge top, a few days after we arrived at Clipperton, and started laying eggs directly on the ground, among coral rocks. In 1898 and 1905 sooty terns were nesting in thousands on the Egg Islands. These birds sometimes occur in incredible numbers but have been known to abandon some islands where they were once very numerous, such as Canton Island (Murphy et al. 1954). They are very noisy and when approached shriek and scream in a deafening manner. Very little guano accumulates in sooty tern rookeries because they usually drop it only over the ocean. The rain of guano, so unpleasant when noddies, boobies or frigate birds are disturbed, is noticeably absent under a flight of sooty terns.

Fairy terns have never been very abundant on Clipperton, all observers mention only a few pairs. In 1958 they had eggs in different parts of the island, on isolated large boulders, and in the coconut palms and ruined quonsets of the southwest side. There is no nest at all, the fairy tern being famous for balancing its egg on a branch or rock, in such a precarious way that it is hard to understand how the bird gets on and off the egg, and how the chick hatches without moving the egg and falling. The chicks of the beautiful little white terns were hatching in the latter part of our stay. When disturbed, adults would flutter about the visitor's head, just beyond reach, and chatter.

Frigate birds in 1958 roosted on the east corner of the island, in a sandy area with scattered boulders and drift material. The adults had almost grown juveniles with them. At the end of our stay, they seemed to be preparing to nest in the coconut trees on the southwest side. Frigate birds had been recorded in 1898 and 1905 and Belcher (1843) had mentioned "frigate pelicans."

The last species of bird to be seen in large numbers at Clipperton in 1958 was the American coot. These dark birds with their curious white beaks were swimming in the lagoon, or walking on shore, and some had built their nests in the sedge beds. Some had chicks swimming behind them. Coots had been observed by Beck in 1901. Together with the ducks reported as common in winter by Snodgrass and Heller and by Beck, but of which we saw none, the coots have probably been very important in increasing the flora of the lagoon. Perhaps all the water phanerogams, the lost Chara and the sedges were brought by these birds in their stomachs or in mud on their feet. The shore birds which were observed in 1958 only as isolated strays (golden plover, bittern, wandering tattler,

sand pipers, and perhaps godwit, etc.) may be more numerous at other seasons and may also transport seeds of water plants. Seabirds are also known to eat plants at times, especially seeds (Guppy, 1906; Ridley, 1930; Fosberg, 1957) and may be responsible for some plant introductions in this way, although transport of prickly or sticky fruits or seeds attached to feathers is probably more frequent. The boobies and noddies may help spread some plants, especially Heliotropium, around the atoll because of their habit of carrying small branches.

Besides their probable role in bringing plant species to the island, the birds of Clipperton may have had other effects on the vegetation. On other widely separated islands it has been shown that birds can damage or even kill vegetation. Vesey-Fitzgerald (1941) suggests that sooty terns may destroy low vegetation or inhibit its growth. Tree-nesting birds damage trees and bushes: On Canton Island frigate birds and red-footed boobies appear to kill some trees or bushes of Scaevola, Cordia and Messerchmidia (Hatheway 1955, pp. 5, 8). On Kapingamarangi, a much wetter atoll, white-capped noddies damage or perhaps kill breadfruit trees (Niering 1956, p. 19). Another interesting example is that of the Chesterfield Islands in the Coral Sea (Cohic, 1959). The small flora of 20 phanerogams forms a vegetation somewhat comparable to that of Clipperton, except for the occurrence of shrubs less than 2 meters tall of Sophora tomentosa, Scaevola sericea and Colubrina asiatica. These woody plants, as well as the few introduced coconut palms, are very much damaged by roosting and nesting frigate birds and red-footed boobies. It is conceivable that on Clipperton, where the seed sources are obviously very poor, the birds, when they were much more numerous in the past, could have prevented the establishment of certain plants, including shrubs and trees. Supposing that rare seeds of such plants could have arrived on the island in drift or by other means and that a few seedlings could have survived in spite of the crabs and developed to maturity, those birds which can nest indifferently on the Rock or on trees would probably have moved over to them and destroyed them. At present the number of birds on Clipperton is small and they have little recognizable direct effect on the vegetation. As mentioned above, they do affect the condition and perhaps multiplication of coconut palms near the Rock. Conversely, the complete absence of trees on the atoll until recent years has successfully precluded the presence of birds that nest exclusively on trees. Whether the recent development of coconut groves will lead to the establishment of new tree-nesting birds, such as red-footed boobies, is of course not known; too many factors are involved. However, this is one of many questions which will make periodic resurveys of the atoll very valuable.

The birds of course have an indirect effect on the vegetation through the enrichment of the soil in phosphate. On other atolls (Cohic 1959), it has been suggested that the very high concentrations of phosphates and nitrates in soils may have deleterious effects on plants. This could not be determined one way or the other on Clipperton.

The impact of the bird population on the island is most striking when one considers the large phosphate deposits, particularly the deep phosphatization of the volcanic rock. Perhaps a detailed study of the

phosphatized trachyte could lead to an estimate of the duration of the process. In any case it is obvious that staggering numbers of birds must have lived on the island for long periods of time. Whether any perceptible phosphate formation occurs at present with the much reduced bird flocks is not known. Fresh guano of course is deposited.

Reptiles:

Morrell (1832) mentioned that green turtles came to Clipperton to deposit their eggs, but there has been no other such report since his time. While the beaches at Clipperton are not the most favorable for turtle nesting, it is not impossible that they once came there. On the voyage from San Diego to Clipperton in 1958 occasional turtles were observed, swimming in the open ocean. In 1934, from the Jeanne d'Arc, thousands of them were observed between Panama and Clipperton (Diben, 1935).

The skinks, Emoia cyanura arundeli, on Clipperton Island were apparently not noticed until collected by Arundel in 1897 (Garman 1899). In 1898 (Heller 1903), and 1905 (Van Denburgh and Slevin 1914) they were especially numerous all over the Rock, rather than on the coral ring. This is a curious observation as the reverse was true in 1958 and the lizards were very numerous in the low vegetation of the island, especially in the Ipomoea blanket. It may well be that they were living in the Rock when lack of vegetation, scarcity of insects, and abundance of crabs made the coral ring too uninviting for them. Their coloring is variable, from almost black to brown with golden-bronze stripes. None of those seen had the blue tails commonly seen on this species elsewhere. Mr. Harbison and I found their oval eggs in old hollow coconuts in the coconut groves and once under a large boulder.

I was working with Mr. Harbison when he doubled the known lizard fauna of Clipperton by catching a gecko (Gehyra mutilata det. W.C. Brown). The protective coloration of this small animal was remarkable, and it took the discoverer's experienced eye to detect its presence among the exposed roots of an old rotting coconut stump. We each caught two, all in daylight, and all near the East face of the Rock, but saw no others.

Invertebrates:

Of the land invertebrates of Clipperton, the great majority were found together in the coconut groves, especially in the small grove at the base of the Rock. Ants, isopods, collembola, spiders, geophilids, earwigs and even small land snails occurred together in the base of coconut fronds, inside damp, rotting husks of old coconuts and in the surface soil. In the old coconuts, a scolopendrid was common and earthworms were extremely numerous in the surface soil and in coconut husks. Flies were common, particularly since dead pigs were lying in the grove. Cockroaches were running through the ruins of the American weather station. Arundel in his diary for 1897 already had mentioned these insects that must have been brought accidentally to the island by man, as have

many of the other land invertebrates. On the northwest side of the island, most of the same invertebrates were also found together under boulders or in soil under vegetation. The two land snails (Opeas sp. and Succinea sp.) often occurred together, live specimens and many empty shells lying on top of the ground, under the layer of coral branches. On the plants, a coccinellid, some grasshoppers, ants and spiders were found, but the invertebrates most obviously affecting the plants were the moths. One small brown moth was very abundant on Cenchrus plants. Larvae of Prodenia sunia (det. H. W. Capps) were eating Corchorus and Sida leaves, those of the tomato hawk (Protoparce sp.) were abundant on Solanum. Most conspicuous was the beautiful large morning-glory hawk moth (Herse cingulata, det. C.F. Harbison), brown with pink wings, hovering in large numbers over the Ipomoea and drinking out of the flowers through its long proboscis. The full grown caterpillars are very large, bright green with brown triangular markings on the sides. After I left Clipperton, they became more numerous and according to Hambly (personal communication) devoured all the leaves and flowers of the morning glory. The cicindelids were extremely abundant along the low lagoon shore, and the damsel flies in the sedge beds.

Among the insects, only the cicindelids, some flies and agrionid dragon flies had been mentioned earlier (Snodgrass and Heller, 1902). In addition bird lice, an earwig and an extremely abundant Machilis had been collected. Early zoological collections, to be sure, were all gathered in a few hours, and some insects may have been missed, but at the same time, it is likely that many insects and other land invertebrates were unable to establish themselves when there was no vegetation on the island, and consequently that the fauna has become larger only recently, in part from accidental introductions by man. Conversely it is curious that some species seem to have disappeared: Machilis mutica (Banks 1901) was extremely abundant in 1898 under the coral pieces scattered on the surface on the island according to Dr. Snodgrass' field notes (personal communication) but has not been collected since.

Two Crustaceans were especially noticeable on Clipperton in 1958. One was the isopod (Cirolana sp.) extremely abundant in the lagoon or at least in its shallow zones near the shores. They were apparently scavenging among the abundant plant material floating in the lagoon, and attached themselves in numbers to legs and bodies, their numerous little bites making it very unpleasant to wade or swim in the lagoon. Here again a species collected in 1898 (Tanais stanfordi) has not been found since.

The red-orange Clipperton land crabs (Gecarcinus planatus) were common in 1958, but infinitely less numerous than in the past, when they covered the land in millions. Their reduction in number was first noted in 1938 by Dr. Waldo Schmitt. In 1958, they lived in holes in the ground, under the vegetation cover, the holes often opening under pieces of coral. They also inhabited what appeared to be natural cracks and holes under the edge of the ledges of consolidated phosphate rock. During the heat of the day, they were mostly hidden, although some could be seen peering from under the ledges if their overhang gave a little shade. In the late afternoon, or during cool, cloudy periods, they would come out, and scramble down lagoon cliffs and over beach ridges apparently on their way to the water. Some were definitely seen dropping into the lagoon waters.

Some shore crabs venture on the land strip and are sometimes found on the lagoon shores. Several species of hermit crabs occur in reef habitats, but the absence of land hermit crabs on Clipperton is striking; yet one or more species are abundant on the majority of other atolls.

Other invertebrates that had not been found before the 1958 survey of Clipperton were the earthworms. Numerous specimens, of rather small size, were found in the dark brown surface soil in the coconut grove at the base of the rock. They also occurred in the damp husks of old coconuts. Elsewhere on the land strip, they could be found under boulders among the vegetation, or, immediately after a rain, on the surface of bare wet sand. According to Dr. G. E. Gates, they represent at least two species (cf. p. 94).

Ecological history

Reconstructing the history of the flora and fauna of Clipperton in detail is of course not feasible, but some changes and interrelations are revealed by an examination of the literature and of the present condition of the island. A chain of ecological cause and effect can thus be tentatively reconstructed. This was discussed in some detail in a paper presented in the Symposium on Modification of biotic balance of island faunas and floras at the Tenth Pacific Science Congress (Honolulu, August 1961) and will be published in the Proceedings of the Symposium. Only the highlights will be given here.

When the island was first described there was some vegetation on it, but in 1858 the vegetation had disappeared, and land crabs were extremely abundant. This condition persisted until 1917 at least. At present, the island has a low, but almost continuous plant cover, and the crabs are much less numerous. Another noticeable change is the fact that the lizards, formerly almost confined to the Rock, are now rare on it, but very numerous in the vegetated area. I believe these phenomena are linked, and can be tentatively explained with the data available. The vegetation disappeared between 1839 and 1858, in the same period when the passes observed by Belcher did. Perhaps the same violent storm that blocked the passes flooded much of the land strip and destroyed most of the vegetation. The land crabs may have eaten the rest, and thereafter devoured every plant that managed to establish itself on the island, meanwhile increasing in number. The large bird colonies may also have helped keep the vegetation from reappearing. The land strip, devoid of vegetation and overrun with red crabs, was not a very suitable habitat for lizards, and they became instead more abundant in the passages and cavities of the Rock. What happened to reverse the process was probably the intervention of man, directly, or more likely indirectly. The guano diggers no doubt destroyed quantities of crab holes, killed many crabs, and at the same time, introduced more plants, for their gardens or by accident, thus already changing the balance somewhat. The multiplication of their pigs, however, which went wild after 1914 is probably the important factor. The pigs had little to eat except crabs, when they were first brought to the island, and must have killed quantities of them. In 1958, some of their droppings were entirely made up of crab shells, and it seems

very likely that the immense numbers of crabs, which gave the island a red color according to some old reports, disappeared in this way. The plants developing from various seed sources, including the added source of human introduction, slowly became too numerous for the remaining crabs and few pigs to keep in check, and the vegetation cover of the island reestablished itself. Meanwhile, the pigs were also feeding on birds' eggs, frightening the nesting birds and apparently bringing about a decrease in the number of seabirds living on the island. The guano diggers must have initiated and helped the process by scraping phosphate rock among bird rookeries, slaughtering birds and taking quantities of eggs. In 1958, the pigs were killed so the birds could make a come-back. Whether this aim will be achieved, or other consequences result, cannot be predicted. It will be interesting to watch the experiment. Quite possibly, the ecological situation had reached a certain stable point, and could have persisted as it was, except for catastrophic changes such as storms. There is no assurance that the bird population will increase, in the absence of the pigs, and other changes may take place instead.

A really complete description of the land ecology of Clipperton, obviously, should include a study of biotic communities, or biocoenoses. In the present state of our knowledge, however, this is not feasible. Too little time was spent on the atoll, and, while the vegetation was studied in some detail, even those animals which could be observed in their association with plants and substratum are mostly not identified, and details of their biology, which presumably were recorded and will be published by the zoologists, are not available.

Similarly, a treatment of the biogeography has had to be omitted. The main purpose of the 1958 collections was to make possible a study of the biogeography of the Clipperton floras and faunas. Earlier papers (e.g. Dawson 1957, Hertlein and Emerson 1953) had called attention to the fact that the marine floras and faunas exhibited an interesting duality of origin: in part Western American (Panamic forms), in part Indo-Pacific. Some notes on the floras are given in my paper on Clipperton Botany (Sachet, 1962), but the land flora (cf. p. 76) failed to be very indicative. The land fauna will probably turn out to be similarly rather disappointing when all the identifications are completed, because many species are probably of human introduction. The first papers to be published on the marine forms collected in 1958 (Allison 1959, Hertlein and Allison 1960a, 1960b) indicate that the duality of origin of the Clipperton fauna is a reality. When all the identifications are available, a general biogeographical description can be written and will undoubtedly be of great interest.

CATALOGUE OF LAND AND LAGOON PLANTS AND ANIMALS

Listed below are systematic enumerations of plants and animals known from Clipperton. Only the land and lagoon species are given here, but a similar catalogue for marine forms will be added elsewhere (Sachet in press.) The list of plants is taken from my paper on Clipperton botany (Sachet 1962) and based on my own collections as well as lists of algae given by Dawson (1957, 1959) and W. R. Taylor (1939). In the case of the animals, it must be pointed out that the collections made prior to 1958 were very small, and that those of 1958 have not yet been reported upon or even completely studied. A few animals collected by myself are included in the list along with the names of the zoologists who identified them. So as to give an indication, at least, of the nature and size of the land fauna, I asked the specialists working on it to give me some preliminary data on the groups under study, and they have kindly done so. Lists of orders, families or species in various groups were provided by Messrs. E. C. Allison (mollusks, ostracods); Wayne Baldwin (fish); T. E. Bowman (isopods); J. S. Garth (crabs); C. F. Harbison (insects and other invertebrates) and David Peterson (rodent). I wish to express to them, and to others with whom I have discussed the Clipperton biota, my most sincere appreciation. Messrs. Allison and Harbison have been especially patient and gracious in answering my numerous queries. Their papers, as well as other systematic treatments of the 1958 collections, are eagerly awaited.

PLANTS

Fungi

Myxomycetes

Dictydiaethalium plumbeum (Schw.) Rost.

Phycomycetes

Cunninghamellaceae
Cunninghamella echinulata (Matruchot) Thaxter
Cunninghamella elegans Lendner

Mucoraceae
Absidia scabra Cocc.
Rhizopus arrhizus Fischer

Piptocephalidaceae
Syncephalastrum racemosum (Cohn) Schroet.

Ascomycetes

Eurotiaceae
Eurotium chevalieri Mangin
Sartorya fumigata Vuill.

Basidiomycetes

Telephoraceae
Corticium lactescens Berk.

Agaricaceae

Fungi Imperfecti

Dematiaceae
Haplographium sp.?

Moniliaceae
Aspergillus flavus Link
Aspergillus flavus-oryzae group
Aspergillus fumigatus Fres.
Aspergillus micro-virido-citrinus Cost. & Lucet
Aspergillus niger series
Aspergillus phoenicis (Cda.) Thom
Aspergillus sydowi (Bain. & Sart.) Thom & Church
Aspergillus sydowi or *versicolor* (intermediate form)
Aspergillus terreus Thom
Aspergillus terreus new var.?
Aspergillus versicolor (Vuill.) Tiraboschi
Aspergillus violaceo-fuscus Gasp.
Geotrichum sp.
Hyalopus sp.
Paecilomyces sp.
Penicillium chrysogenum Thom
Penicillium citrinum Thom
Penicillium commune Thom
Penicillium cyclopium Westl.
Penicillium funiculosum Thom
Penicillium funiculosum series
Penicillium lanosum Westl.
Penicillium meleagrinum Biourge
Penicillium oxalicum Currie & Thom.
Penicillium (near *P. piscarium* Westl.)
Penicillium sp.
Trichoderma viride Pers. ex Fr.

Tuberculariaceae
Fusarium sp.

Lichenes

Pyrenocarp lichen

Buelliaceae
Rinodina sp.

Physciaceae
Pyxine sp.

Algae

Myxophyceae

Chroococcaceae

Anacystis aeruginosa (Zanard.) Dr. & Daily
Anacystis montana (Light f.) Dr. & Daily
Chroococcus turgidus (Kützing) Nägeli
Gomphosphaeria aponina Kützing
Microcystis flos-aquae (Wittrock) Kirchner

Chamaesiphonaceae

Entophysalis deusta (Menegh.) Dr. & Daily
Entophysalis granulosa Kützing

Stigonemataceae

Mastigocoleus testarum Lagerh.

Nostocaceae

Nostoc sp.

Scytonemataceae

Scytonema hofmannii Ag.

Rivulariaceae

Amphithrix violacea (Kütz.) Born
Calothrix crustacea Thur.
Calothrix parietina (Naeg.) Thuret
Calothrix stellaris Bornet & Flahaut

Oscillatoriaceae

Lyngbya aestuarii (Mertens) Liebmann
Lyngbya semiplena (Ag.) J. Ag.
Lyngbya confervoides Ag.
Lyngbya guaymasensis Drouet
Lyngbya lagerheimii (Möbius) Grunow
Lyngbya versicolor (Wartmann) Gomont
Microcoleus chthonoplastes (Fl. Dan.) Thur.
Plectonema nostocorum Born.
Plectonema terebrans Born. & Flah.
Schizothrix heufleri Grun.

Chlorophyceae

Desmidiaceae

Closterium parvulum Nägeli
Closterium parvulum Nägeli forma
Closterium parvulum near var. majus West
Cosmarium clippertonensis Taylor
Cosmarium subprotumidum Nordstedt, forma

Oocystaceae

Oöcystis solitaria Wittrock approaching forma major Wille

Oedogoniaceae
Oedogonium sp.
Oedogonium sp.

Sphaerellaceae
Protococcus grevillei (Ag.) Crouan

Characeae
Chara sp.

Pyrrophyceae

Peridiniaceae
Glenodinium sp.

Bryophyta

Musci (Mosses)

Bryaceae
Bryum sp.
Bryum argenteum Hedw. var. *lanatum* (Palisot de Beauv.) BSG.

Leucobryaceae
Octoblepharum albidum Hedw.

Spermatophyta

Potamogetonaceae
Potamogeton pectinatus L.
Ruppia maritima L.
Zostera marina var. *latifolia* Morong?

Najadaceae
Najas marina L. var. *latifolia* A. Br.

Gramineae
Cenchrus echinatus L. (glabrous form)
Dactyloctenium aegyptium (L.) Willd.
Eragrostis amabilis (L.) W. & A.
Eragrostis ciliaris (L.) R. Br.

Cyperaceae
Eleocharis geniculata (L.) R. & S.
Eleocharis mutata (L.) R. & S.
Hemicarpha micrantha (Vahl) Pax
Scirpus rubiginosus Beetle

Palmae
Cocos nucifera L.

Portulacaceae
Portulaca oleracea L.

Cruciferae
Brassica juncea L.

Leguminoseae
Caesalpinia sp.
Canavalia sp.
Mucuna sloanei Fawc. & Rend.?
Phaseolus adenanthus Mey.?

Euphorbiaceae
Phyllanthus amarus Sch. & Thonn.

Sapindaceae
Sapindus saponaria L.?

Malvaceae
Sida rhombifolia L.

Tiliaceae
Corchorus aestuans L.

Sterculiaceae
Waltheria indica L.

Convolvulaceae
Ipomoea pes-caprae subsp. *brasiliensis* (L.) v. Ooststrom
Ipomoea triloba L.

Solanaceae
Nicotiana glauca Graham
Solanum nigrum L. var. *americanum* (Mill.) O. E. Sch.

Boraginaceae
Heliotropium curassavicum L.

Compositae
Conyza bonariensis (L.) Cronq.
Eclipta alba (L.) Hassk.

Drift seeds

Palmae
Astrocaryum sp.
Several unidentified endocarps from cocoid palms

Leguminosae
Caesalpinia bonduc (L.) Roxb.
Caesalpinia major (Medic) Dandy & Excell
Canavalia rosea (Sw.) DC.
Dioclea megacarpa Rolfe?

Leguminosae (con't)

Dioclea reflexa Hook.?
Entada gigas (L.) Fawc. & Rendle
Mucuna mutisiana (HBK) DC.?
Mucuna sloanei Fawc. & Rendle
Mucuna urens (L.) DC.?
Strongylodon lucidus (Forst.f.) Seem.?

Sapindaceae

Sapindus saponaria L.

Convolvulaceae

Merremia tuberosa (L.) Rendle

ANIMALS

This list is compiled mostly from the literature, but includes some unpublished records. References or other sources of information are given in parentheses for each species or any higher group to which they apply. When several papers list the same species, usually only the most recent one is mentioned. The species or groups recorded from Clipperton for the first time as a result of the 1958 survey are marked with an asterisk.

Annelida

*Oligochaeta
(Earthworms, det. Dr. G. E. Gates, cf. p. 86)

Megascolecidae

Dichogaster bolaui (Michaelsen)
Pontodrilus bermudensis Bedd.?--(specimens poorly preserved).

Mollusca

Gastropoda
(Bartsch and Rehder 1939, Hertlein and Emerson 1953)

Aspidobranchia

Neritidae

Nerita plicata L.--just above high tide

Pectinibranchia

Littorinidae

Littorina schmitti Bartsch and Rehder--just above *Nerita* level

Pulmonata

Subulinidae
Opeas oparanum Pfeiff.--common on ground

*Succineidae
Succinea sp. --common on ground (det. E.C. Allison).

Arthropoda

Crustacea

Ostracoda

*3 species found in lagoon in 1958

Malacostraca

Tanaidacea

Tanaidae
Tanais stanfordi H. Richardson--lagoon (Richardson 1901, not found again in 1958).

Isopoda

Flabellifera
*Cirolanidae
Cirolana sp. --lagoon (det. Thomas E. Bowman).

Oniscoidea
Ligiidae
Ligia exotica (Roux)--splash zone (Richardson 1901).

*Terrestrial isopods of several species collected in 1958.

Amphipoda

Talitridae
Orchestia marquesana Stephensen--old bird nest (Shoemaker 1942).

Decapoda

Brachyura
Grapsidae
Geograpsus lividus (M.-E.)--lagoon (Rathbun 1902).
Pachygrapsus minutus (M.-E.)--shore (Schmitt 1939).

Gecarcinidae
Gecarcinus planatus Stimpson--land (Schmitt 1939).
Gecarcoidea lalandei (M.-E.)--in guano from Clipperton (Lenz 1901).

Caridea

Palaemonidae

Palaemon (*Palaemon*) *gladiator* Holthuis--lagoon (Rathbun 1902, Holthuis 1952, not found again in 1958).

Arachnida

*Araneida

Argiopidae

Araneinae

Tetragnathinae

Tetragnatha sp. --(det. R.E. Crabill, Jr.)

Pholcidae

1 species

Salticidae (Attidae)

Acarina--old booby nest (Wharton 1941)

Mesostigmata

Parasitoidea

Ascaidae

Asca quinquesetosa Wharton

Laelaptidae

Atricholaelaps clippertonensis Wharton

Eulaelaps roosevelti Wharton

**Cosmolaelaps* sp.--(det. E.W. Baker).

*1 new species of Parasitoidea obtained in 1958

Uropodoidea

Uropodidae

Uropoda spp.

**Fuscuropoda* sp.--(det. E.W. Baker).

*Sarcoptiformes

Analgesidae

Proctophyllodidae

3 species, one new.

Oribatei

Oribatulidae

Scheloribates fimbriatus calcaratus Jacot

Scheloribates indica Oudemans

Chilopoda

(Chamberlin 1914, 1924)

Geophilomorphia

Mecistocephalidae

Mecistocephalus parvus Chamberlin

Scolopendromorpha

Cryptopidae
Cryptops navigans Chamberlin

*Scolopendridae
Rhysida sp. --(det. R.E. Crabill, Jr.).

Insecta

Thysanura

Machilidae
Machilis mutica Banks--abundant on land (Banks 1901, not found in 1958).

*Collembola

Entomobryidae
2 species obtained in 1958

Sminthuridae
1 species

Odonata

Coenagrionidae--(Snodgrass and Heller 1902 as "agrionid")
Ischnura ramburii ramburii (Selys)--(det. C.F. Harbison).

Blattaria

Blattidae--(cockroaches mentioned in Arundel's 1897 diary)
1 species taken in 1958.

*Orthoptera

Tettigoniidae
Conocephalinae
1 species taken in 1958

Dermaptera

Forficulidae
Anisolabis annulipes Lucas--(McNeill 1901).

*Hemiptera

Homoptera-Fulgoroidea
Areopodidae
1 species taken in 1958

Heteroptera

Pentatomidae
1 species

Lygaeidae
1 species

Nabidae
1 species

Gerridae
1 species

*Corrodentia

Perientomidae
1 species

Procidae
1 species

Mallophaga--from sea birds (Thompson 1938-39).

Menoponidae
Actornithophilus milleri (Kellogg and Kuwana)
Colpocephalum angulaticeps Piaget
Menopon incertum Kellogg
Menopon singularis Kellogg and Kuwana

Philopteridae
Anatoecus dentatus (Scopoli)
Columbicola columbae (L.)
Degeeriella birostris (Giebel)
Degeeriella gloriosa (Kellogg and Kuwana)
Degeeriella lepida (Kellogg and Kuwana)
Degeeriella obtusa (Kellogg and Kuwana)
Degeeriella separata (Kellogg and Kuwana)
Degeeriella vulgata (Kellogg)
Pectinopygus gracilicornis (Piaget)
Pectinopygus sulae (Rudow)
Saedmundssonia peristictus (Kellogg and Kuwana)
Saedmundssonia melanocephala (Nitzsch).

*Lepidoptera

Heterocera

Sphingidae
Herse cingulata Fabr.--(det. C.F. Harbison)
Protoparce sp.--(det. H.W. Capps).

Noctuidae
Prodenia sunia (Guinée)--(det. H.W. Capps).
7 species obtained in 1958

Pyralidae
2 species obtained in 1958

Diptera--(recorded as Diptera by Snodgrass and Heller 1902).

*Sciaridae
1 species obtained in 1958

*Dolichopodidae
1 species

*Phoridae
1 species

*Drosophilidae
1 species

*Tethinidae
1 species

*Milichiidae
Desmometopa sp.--(det. C.W. Sabrosky).
2 species taken in 1958

*Chloropidae
1 species

*Ephydridae
2 species

*Sphaeroceridae
1 species

*Muscidae
1 species

*Sarcophagidae
1 species

*Hippoboscidae
1 species

Coleoptera

Cicindelidae
Cicindela bifasciata [probably misspelling for trifasciata Fabr.]--(Van Dyke 1953).

*Staphylinidae
1 species

*Coccinellidae
Hippodamia convergens Guér.--(det. E.A. Chapin).

*Tenebrionidae
1 species collected in 1958

*Hymenoptera

Formicidae

<u>Tetramorium</u> <u>simillimum</u> (F.Sm.)--(det. M.R. Smith).
<u>Triglyphothrix</u> <u>striatidens</u> (Emery)-- " "
4 species taken in 1958

Chordata

Pisces

*Acanthuridae

1 species

*Pomacentridae

1 species

Gobiidae

<u>Bathygobius</u> <u>arundelii</u> (Garman)--lagoon (Ginsburg 1947).

Reptilia

Testudinata

Cheloniidae

<u>Chelonia</u> <u>mydas</u> L.--green turtle (Morrell 1832, not reported on island since).

Sauria

*Gekkonidae

<u>Gehyra</u> <u>mutilata</u> (Wiegmann)--(det. W.C. Brown).

Scincidae

<u>Emoia</u> <u>cyanura</u> <u>arundeli</u> (Garman)--(W.C. Brown 1954).

Aves

Procellariiformes

Procellariidae

<u>Pterodroma</u> spp.--petrels (several spp. recorded from vicinity of Clipperton, at sea, by Loomis 1918).
<u>Puffinus</u> <u>auricularis</u> Townsend--Townsend's shearwater (Am. Ornith. Union 1957).

Pelecaniformes

Phaetontidae

<u>Phaëton</u> spp.--tropic-birds (several spp. recorded from vicinity of Clipperton, at sea, by Gifford 1913).

Sulidae

Sula dactylatra californica Rothschild--masked booby, blue-faced booby (Am. Ornith. Union 1957).

Sula leucogaster nesiotes Heller and Snodgrass--brown booby (Wetmore 1939).

Sula variegata Tschudi--Peruvian booby (Beck 1907).

Fregatidae

Fregata minor Gmelin--great frigate (Snodgrass and Heller 1902, as *F. aquila*).

Ciconiiformes

Threskiornithidae

Plegadis ?--a black ibis sighted (Beck 1907).

Anseriformes

Anatidae--(Beck 1907, Am. Ornith. Union 1957).

Anas acuta L.--pintail

Anas discors discors L.--blue-winged teal

Aythya valisineria (Wilson)--canvasback

Mareca americana (Gmelin)--baldpate, American widgeon

Spatula clypeata (L.)--shoveller

Gruiformes

Rallidae

Fulica americana americana Gmelin--coot (Beck 1907)

Charadriiformes

Charadriidae

Squatarola squatarola (L.)--black-bellied plover (Beck 1907, Am. Ornith. Union 1957).

Scolopacidae

Heteroscelus incanus (Gmelin)--wandering tattler (Gifford 1913)

Numenius phaeopus hudsonicus Latham--Hudsonian curlew (Beck 1907).

Laridae--(Wetmore 1939)

Anous stolidus ridgwayi Anthony--common noddy

Anous minutus diamesus (Heller and Snodgrass)--white-capped noddy

Gygis alba candida (Gmelin)--fairy tern

Sterna fuscata crissalis (Lawrence)--sooty tern

Passeriformes

Hirundinidae

Hirundo rustica erythrogaster Boddaert--barn swallow (Heller and Snodgrass 1902)

Small land birds were recorded on Clipperton by Morrell (1832) and Taylor (1948). In 1958, some new records of land, shore and sea birds were made, 16 species in all according to Stager (1959).

Mammalia

Pinnipedia

Otariidae

Arctocephalus sp.--fur-seal (Morrell 1832, not reported since).

Phocidae

Mirounga sp.--sea elephant (Morrell 1832, not reported since).

Artiodactyla

Suidae

Sus scrofa L.--pig (introduced about 1897, destroyed in 1958).

*Rodentia

Muridae

Mus sp.--mouse (1 mouse seen in ruins of Weather station in 1958).

Primata

Hominidae

Homo sapiens L.--occasional visitors.

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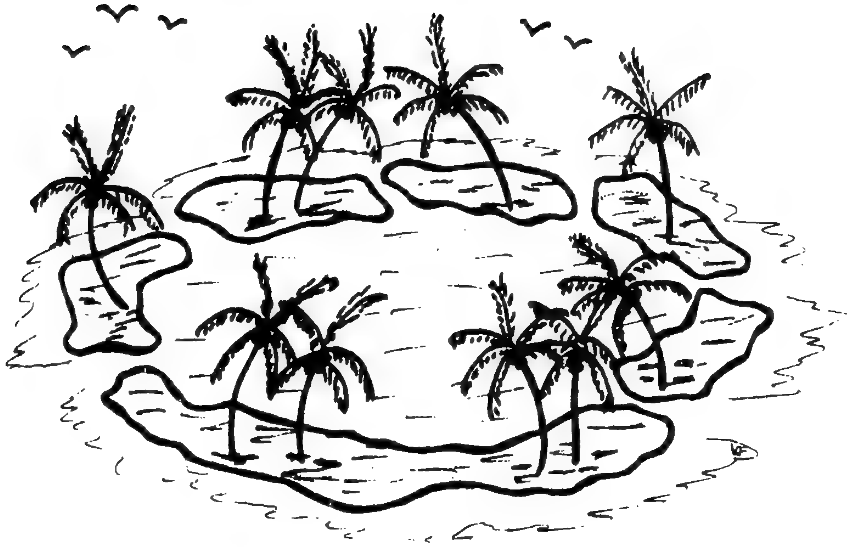
No. 87 June 30, 1962

ATOLL RESEARCH BULLETIN

Three Caribbean atolls: Turneffe Islands, Lighthouse Reef, and Glover's Reef, British Honduras

by

D. R. Stoddart



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THE PACIFIC SCIENCE BOARD

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Preliminary Results of Field-work carried out during

THE CAMBRIDGE EXPEDITION TO BRITISH HONDURAS 1959-60
December 1959 to July 1960

and

THE BRITISH HONDURAS CORAL REEFS AND ISLANDS EXPEDITION 1961
May 1961 to July 1961
(Sponsored by Coastal Studies Institute, Louisiana State University, and Office of Naval Research, Washington)

ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past fourteen years.

The preparation and issuance of the Atoll Research Bulletin is assisted by funds from Contract N7onr-2300(12).

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Washington 25, D.C., U.S.A.

CONTENTS

FIGURES

I. INTRODUCTION

In his "Checklist of Atolls", Bryan (1953) listed a total of 27 atoll-like structures in the Caribbean, three of which are located off the coast of British Honduras (cf. Cloud, 1957, 1010-1011). The Turneffe Islands he considered "not sufficiently surveyed to determine form"; Lighthouse Reef he described as "atoll-like, 5 cays"; and Glover's Reef as "sunken atoll-like, 5 small cays". Until recently this survey represented the total of our knowledge of these atolls, perhaps the least well-known and probably the finest structures of their type in the Caribbean Sea.

Location

Location of the atolls on published charts derives from surveys of the period 1820-1830, and no attempt is made to show details of form or topography. Figure 1 shows the atolls as surveyed by Captain Richard Owen, from a manuscript map (H57) dated October 1830 in the possession of the Hydrographic Department, Admiralty; in many respects it is more detailed than subsequently published charts, which are based on it. Figure 2 attempts to combine published charts of the location of the atolls with maps of detailed form derived from air photographs. These airphoto maps are reduced from the large scale maps included with this paper in the accounts of each individual atoll. It will be seen that Lighthouse Reef as shown on figure 2 corresponds well with representations on charts; Turneffe Islands correspond in gross form, but much lagoon detail is added; while Glover's Reef, though broadly similar on figures 1 and 2, differs considerably in figure 2 from published charts.

The following survey of the location of the atolls is derived from published charts. The coast of British Honduras is fringed by a submerged coastal shelf edged by a well-developed barrier reef. In the latitude of Belize (17°30'N), the shelf lagoon is 8 miles wide. Beyond the barrier in this latitude, a channel 11 miles wide separates the shelf from Turneffe. This channel varies in width from 5½ to 14 miles, being narrowest in the centre. Turneffe bank itself has a maximum length of 30.5 miles along its NNE-SSW axis; its greatest width, at the latitude of Soldier Cay, is 10 miles, and the average width 5-6 miles. It covers approximately 205 square miles, and its co-ordinates, from charts, are:

North extremity (drying reef)	17°38'00"N
South extremity (Cay Bokel)	17°09'00"N
Eastern extremity (northeast corner)	87°44'30"W
Western extremity (west side)	87°57'30"W

Lighthouse Reef is situated east of Turneffe, from which it is separated by a channel 11½ to 18 miles wide; again the channel narrows towards the middle and widens at its ends. The distance between Cay Bokel (south end of Turneffe) and Hat Cay (south end of Lighthouse

Reef) 19 miles. The maximum length of Lighthouse Reef along its NNE-SSW axis is 22 miles, and its width varies from 2 to 4 3/4 miles. The approximate area is 78.5 square miles, and its co-ordinates, from charts, are:

North extremity (Sandbore Cay)	17°28'30"N
South extremity (reef)	17°07'00"N
Eastern extremity (northeast reef)	87°27'00"W
Western extremity (southwest reef)	87°36'30"W

Glover's Reef is located 15 miles SSE of the south end of Turneffe, and 13½ miles SSW of the south end of Lighthouse Reef. Like Turneffe it is separated from the coastal shelf and barrier reef by a channel 13½-17 miles wide, narrowest at its northern end, between Glover's Reef and Cay Glory. Glover's Reef is aligned NNE-SSW, following the trend of the southern barrier reef. South of Glover's Reef, the barrier reef swings eastwards, forming the pronounced elbow at Gladden Spit, and then westwards to form the bight between Glover's Reef and the barrier. The channel thus formed on the south side of Glover's Reef, between it and the barrier, is 13½ miles wide. The bank has a greatest length along its main axis of 16 miles, and averages 5-6½ miles in width. Its area is some 82 square miles. Co-ordinates from charts are:

North extremity (northeast reef)	16°55'30"N
South extremity (southern reef-entrance)	16°42'00"N
Eastern extremity (northeast corner)	87°41'30"W
Western extremity (southwest corner)	87°52'00"W

Approaches

All three banks are steep-to, and must be approached with caution, though Turneffe is normally visible with the naked eye at a distance of 6-7 miles (from sea-level). There are two lighthouses on Turneffe: one on Mauger Cay near the north end, a tower 64 feet high, location 17°36'30"N, 87°46'00"W; the other is on Cay Bokel, at the southern extremity of the reef, location 17°09'30"N, 87°54'00"W. Cay Bokel light is not visible from the NNW and NE because of intervening mangrove.

Lighthouse Reef also has two lights: one, 70 feet high, on Sandbore Cay at the north end, 17°28'00"N, 87°29'00"W; the other, 80 feet high, on Half Moon Cay, near the southern end, 17°12'00"N, 87°31'00"W. Both are partly obscured by cays to the east and southeast. There are no lights on Glover's Reef, but the lights on the other atolls are highly dependable.

There is good anchorage in depths of 9 fathoms near Cay Bokel, at the south end of Turneffe, and also in the southern entrance of Glover's Reef. There are no satisfactory anchorages for large vessels at Lighthouse Reef, with the possible exception of the bay lying west and south of Half Moon Cay. Further details on lights and anchorages are given by the West Indies Pilot, Vol. 1, 11th edition, 1956, p. 459-462.

Discovery

There are no pre-Columbian historical remains on either Lighthouse Reef or Glover's Reef, though Maya shell-middens are reported from the Calabash Cays area and Northern Bogue on Turneffe (Romney and others. 1959, fig. 10). It is not impossible that the Mayas did visit the two outer atolls on occasion in canoes, since they appear to have carried on a sea trade between Yucatan and the Bay Islands (Chamberlain, 1953), and in fact this is suggested by the Turneffe middens, located at the eastern exits of the Turneffe lagoons still used by fishermen making for Lighthouse Reef. There is, however, no evidence of permanent settlement similar to that found on some cays within the British Honduras barrier reef.

The east coast of the Yucatan Peninsula between Bahia Chetumal and Golfo Dulce was first explored by Francisco de Montejo in 1528 and his lieutenant Davila in 1532-3 (Chamberlain,1948, 1953). No permanent Spanish settlement seems to have been established on this coast between Salamanca de Bacalar and the Sarstoon River (Humphreys,1961), but the coastline and reefs must have become well-known to Spanish navigators travelling between Honduras, northern Yucatan and Cuba in the sixteenth and seventeenth centuries. English logwood cutters began to gather on the Belize River during and after the period 1640-1660, and this led to an international tension not conducive to the sharing of hydrographic information. There seems little doubt that Spanish knowledge of the coast and reefs was treated as a military secret, and their maps remained unpublished in Seville. The fashion for the published charts seems to have been set by Herrera's _Description del destricto del Audiencia de Nueva Espana_ of 1601-15 (Vindel, 1955, 69-70), in which a number of coastal islands are named, from south to north, off the coast of what is now British Honduras: Ilbob, Lamanay, Pantoja, Quitasueno, and El Triangulo. On De Laet's map of 1625 (Comision de Limites, 1928), these appear as Ylbob, Lamanay, Zaratan, Pantoja, and Quitazuenho: with the possible exception of Lamanay (Turneffe?) none can be certainly identified today. These names regularly appear on the charts of Blaeu, Vooght, Visscher, Morden and others until c. 1720, and at least one map with these names appeared as late as 1793 (Baret-Elwe, 1793).

Nautical knowledge has by this time far outstripped the cartographers. The words 'Terre Neuf' (Turneffe) first appear (in addition to Lamanay and Zaratan) on a chart by Vooght in 1698. Manuscript maps reproduced by Calderon Quijano (1944) from the Seville archives show a Spanish understanding of the topography of the three atolls not approached in England until the nineteenth century. The _Plano de la Costa Oriental de Yucatan_ of 1749, though poorly reproduced, shows the three atolls in their correct relations, with the cays on Lighthouse and Glover's Reefs clearly marked; Turneffe appears as 'Terra Nef'. The _Plano de la Costa de Honduras_ of 1756 shows 'Terra Nef', 'Quattro Cayos' (Lighthouse Reef), and 'Longorif' (Glover's Reef), these last two names appearing on charts for the first time. The use of the name 'Long Reef' for Glover's Reef seems to have been general in the early eighteenth century, and Winzerling (1946) suggests that the name 'Glover' derives from a pirate of that name who made the atoll his own, though little else is known about him. The present name was used on the first Admiralty charts, and the old

name has been forgotten. Quattro Cayos, Four Cays, or Eastern Reef was used for Lighthouse Reef until the Half Moon Cay lighthouse was built in 1821 (Honduras Almanack,1830). On both these manuscript charts the Turneffe lagoon is filled with shapeless islands, and the same is true for Glover's Reef on the 1756 map. On an undated map of the same period, Mapa de el ceno de Honduras (Calderon Quijano, 1944, Plate 17), however, the distribution of land on Turneffe is shown with an exactitude and clarity not achieved again for over 150 years; it may be compared with recent English official maps (e.g. in Romney and others,1959), and shows more information on the interior of Turneffe, though on a small scale, than present nautical charts (cf. Admiralty chart 959, 1929).

The Spanish discoveries penetrated slowly into the English literature, though a Spanish map was used by Speer in the first edition of his West India Pilot (1766), and greatly improved in the second (1771). Speer was clearly well acquainted with the waters he described. For the first time in his work an individual cay is named on Turneffe (Quibiquel in 1776, Kay Boquel in 1771); Glover's Reef appears as Longorriff or Arrecife Largo with three un-named cays in 1766, and received its present name for the first time on a chart in 1771; with Lighthouse Reef or Quattro Cayos del Sur (1766) shows North Four Kays and South Four Kays (including Hat Kay) in 1771. Nevertheless, Speer's map is crude compared with the extraordinary charts of the Gulf of Honduras prepared by Thomas Jefferys (died 1771) and published in 1775, 1792 and 1800. According to the editors of the 1775 West India Atlas, "The English charts, both manuscript and printed, are more numerous than the Spanish materials. On the continent they have chiefly been of use to determine the bay of Honduras, the Mosquito-Shore, and Florida. We had so considerable a quantity of manuscripts...upon the Bay of Honduras, properly so called, ...that there is nothing more to be wished for in the exactness of this map" (Jefferys, 1775, p. iii).

On the first Jefferys map of 1775, Turneff is marked, with Key Bokel in the south; in 1792 and 1800 Cayo de Muger or Mauger Key was added in the north. Glover's Reef appears in 1775 as Arrecife Largo, Glovers Reef or Long Reef; The Two Spots are marked at its northern end, and five un-named cays in the south; and there is little change in later editions. Lighthouse Reef is termed Four Keys Reef in 1792 and 1800. In the earliest map, Jefferys includes North Two Keys, with The Bushy Spot (modern Northern Two Cays and Sandbore Cay), and in the Southern Four Cays on this atoll he names North Key (Saddle Cay), Easternmost Key (Half Moon Cay), Halfmoon Key (Long Cay), and Hat Key. The misnaming of Half Moon Cay continues in the 1792 and 1800 editions.

Jefferys' maps remained the best available until the detailed survey of the east coast of Yucatan by the British Admiralty in the late 1820s and early 1830s. This was begun by Anthony de Mayne, HMS Kangaroo, with a survey of Belize harbour in 1828, which remains in manuscript. Commander Richard Owen and Commander Edward Barnett produced a preliminary survey of the whole coast in 1830 (Admiralty ms charts H57), and this still remains the basis of current charts of the atolls. Barnett went on to map Banco Chinchorro atoll in detail in 1839, and this chart was published in 1850, and Owen continued work on the coastal shelf and barrier reef, but paid no more attention to the three British Honduras atolls.

Subsequent surveyors, including the most recent (HMSS Vidal, Capt. E. G. Irving, 1957), have all been restricted to the coastal shelf and Belize harbour. Thus the representations of the atolls on present charts date entirely (with the exception of the west coast of Turneffe opposite Belize, and of recent charts of Glover's Reef) to Owen's sketch surveys of over a century ago. Glover's Reef on current Admiralty charts is said to be derived from small-scale American charts, and comparison with Owen's 1830 manuscript, and with the air photo plot, shows that the change was not for the better.

Scientific studies on the atolls

Owen carried no naturalist on his ship, and published accounts of his work are sparse (Owen, 1838; Bird Allen, 1841). Darwin includes information from Allen in his Structure and Distribution of Coral Reefs (1842), but the letters from Allen to Darwin describing the reefs cannot now be found. Few naturalists, apart from ornithologists (Salvin, 1894; Schmidt, 1941; Verner, 1957), have since visited the area. Sapper crossed Turneffe and visited Long Cay, Lighthouse Reef, in 1894-96 (Sapper, 1899, map 1), but does not seem to have published any description. Ower, a Government geologist, touches briefly on the reefs in several papers (1927, 1928); Dixon, also a Government geologist, visited Turneffe with the British Honduras Land Use Survey Team (Dixon, 1956; Romney and others, 1959), but gives no general account of the atolls. Vermeer (1959) also visited Half Moon Cay and Long Cay on Lighthouse Reef in 1957 as part of a reconnaissance study of the cays of British Honduras sponsored by the Office of Naval Research, Washington. Neither Alexander Agassiz (1894) nor T. Wayland Vaughan (1919), though often referring to the east coasts reefs of Yucatan in support of their own theories, ever visited the area. No geologist or zoologist (with the exception of the ornithologist Salvin and a lizard-collecting expedition referred to by Schmidt (1941)) ever seems to have visited Glover's Reef.

Present study

This paper is based on several visits to the atolls in the course of two expeditions. Turneffe was visited twice and Lighthouse Reef once, in early 1960, in the course of the Cambridge Expedition to British Honduras 1959-60, led by J. E. Thorpe (CEBH, 1960; Carr and Thorpe, 1961). My main study on this occasion was the study of the form and development of the sand cays on the British Honduras reefs as a whole. Thirteen cays were mapped on Turneffe, and three on Lighthouse Reef. In the light of results obtained on this expedition a second visit was seen to be necessary, and it is a pleasure to acknowledge the help of the Office of Naval Research, Washington, and the Coastal Studies Institute, Louisiana State University, in making this possible. I am grateful to Miss Evelyn L. Pruitt, Head, Geography Branch, Office of Naval Research, for much encouragement with the 1961 expedition. During this second expedition (British Honduras Coral Reefs and Islands Expedition 1961) I was again concerned with mapping cays on both the atolls and the barrier reef. Glover's Reef and Lighthouse Reef were each visited twice, and Turneffe once, and another 9 cays mapped on them, but an effort was also made to collect information relat-

ing to the atolls generally. In particular, the reef transects described in Section IV were made on the second expedition. The routes followed on these excursions are shown on figure 3.

On the first expedition I had the field assistance of J. D. Poxon, B. A., Selwyn College, Cambridge, who also navigated our yacht Tortuga, and on the second one of S. P. Murray, of Louisiana State University; their help has been invaluable. I would also like to thank Professor J. A. Steers, of Cambridge, under whose direction this work has been carried out, and Professor R. J. Russell, of Baton Rouge; Dr. F. R. Fosberg, who kindly identified my plants; and Dr. Fosberg, Dr. Cyril Dixon (Geological Survey, British Guiana) and Dr. D. A. Vermeer (University of California), for discussion of many points.

It is impossible to make individual acknowledgment of all the help received on these expeditions from many other sources, but mention must be made of the assistance from the then Governor of British Honduras, Sir Colin Thornley, the Chief Secretary and Executive Council, and the Comptroller of Customs, Mr. David Bradley, for customs exemption and other help; from the British Museum (Natural History) in the supply of plant-collecting materials; from Marine Electronics Ltd., London, for supply of an echo-sounder; and from the many commercial organisations and individuals, detailed elsewhere, for their help with equipment, general supplies and finance. This work has been supported since 1959 by a grant from the Department of Scientific and Industrial Research, London, held at the Department of Geography, Cambridge, England.

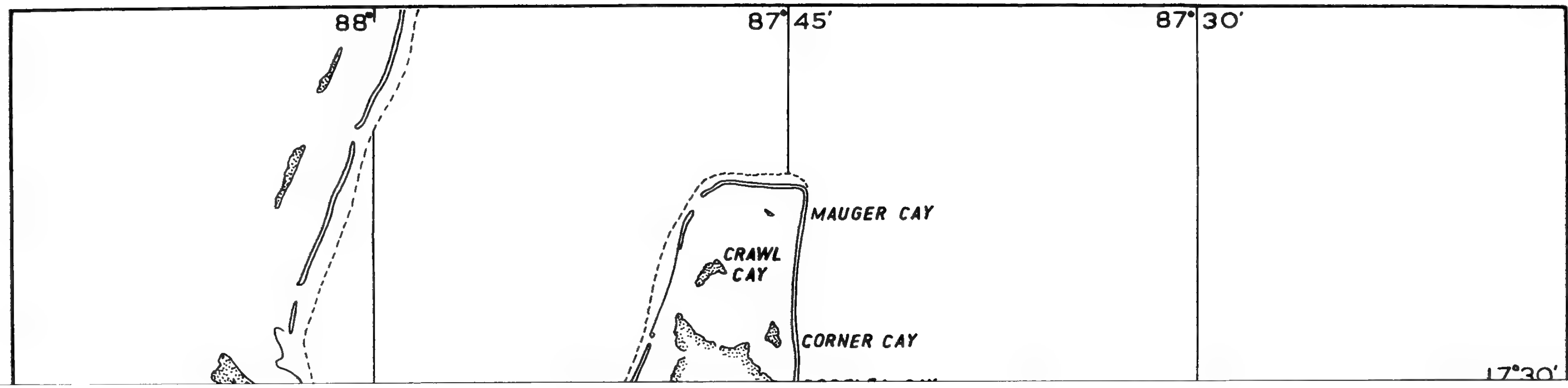
Miss Pruitt kindly made available, through Coastal Studies Institute, the air photographs on which figures 27 and 37 are based. I am indebted to Admiral E. G. Irving, Hydrographer to the Navy, Hydrographic Department, Admiralty, London, for permission to base figures 1, 14 and 32 on unpublished Admiralty manuscripts, and for giving me access to the Hydrographic Department Archives at Cricklewood.

Dimensions of Pacific and Caribbean Atolls compared

Atoll	Length miles	Breadth miles	Area square miles	Maximum depth fathoms	Land area square miles	
Bikini	26	15	243	32	3.4	(1)
Rongelap	33	20	396	35	3.2	(1)
Eniwetok	25	20	360	35	2.5	(1)
Rongerik	11	11	57	26	0.53	(1)
Kapingamarangi	8	6.3	31.7	43	0.4	(2)
Raroia	27.5	8.75	156	30	8.2	(3)
Turneffe	30.5	10	205	3.5	48	(4)
Lighthouse Reef	22	4.7	78.5	5*	3	(4)
Glover's Reef	16	6.5	82	24	0.3	(4)

* Depth of blue hole: 78 fathoms

Sources:
1. Emery, Tracey and Ladd, 1954.
2. Wiens, 1956.
3. Newell, 1956.
4. This paper


88°
87° 45'
87° 30'
MAUGER CAY
CRAWL CAY
CORNER CAY
17°30'

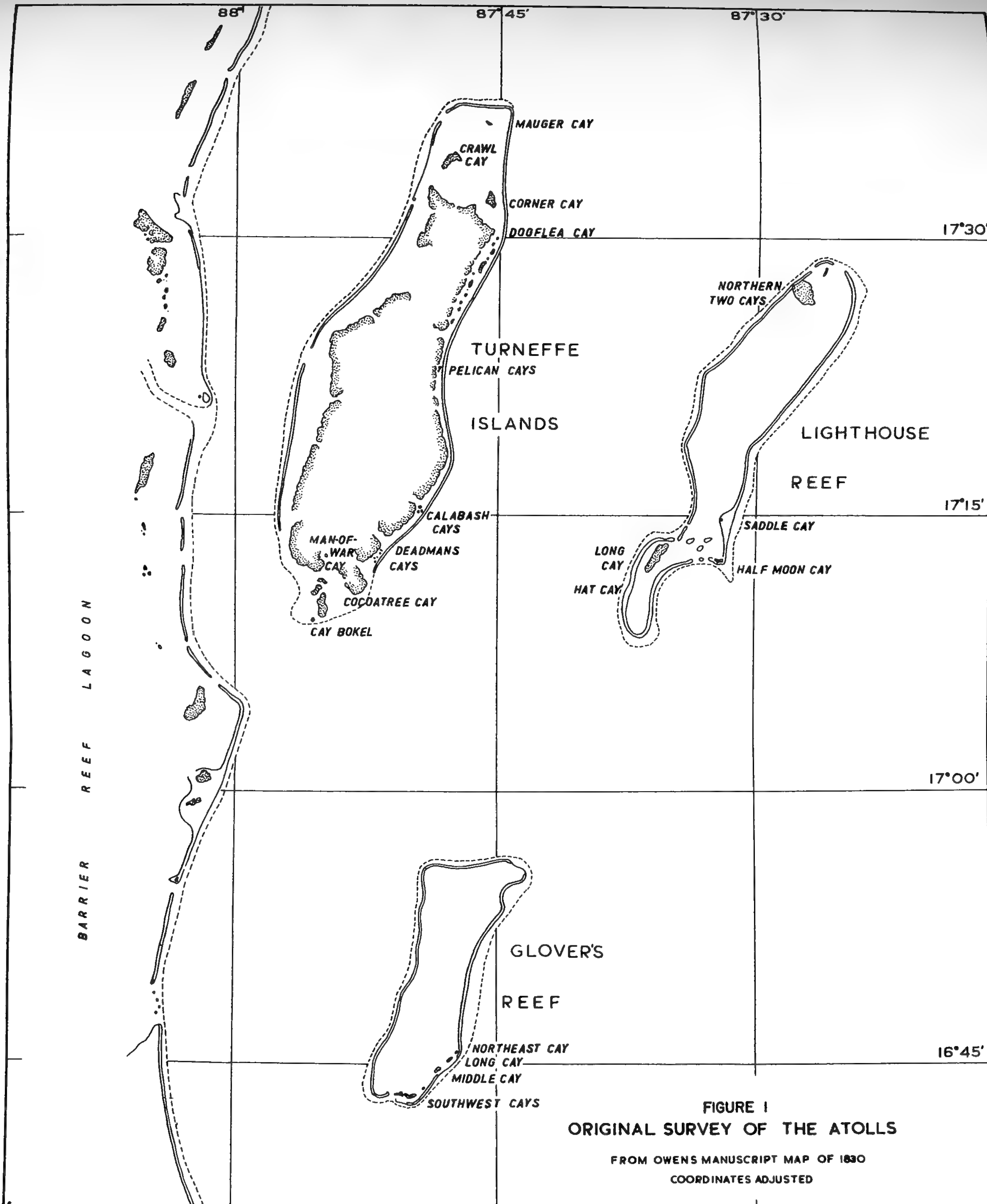
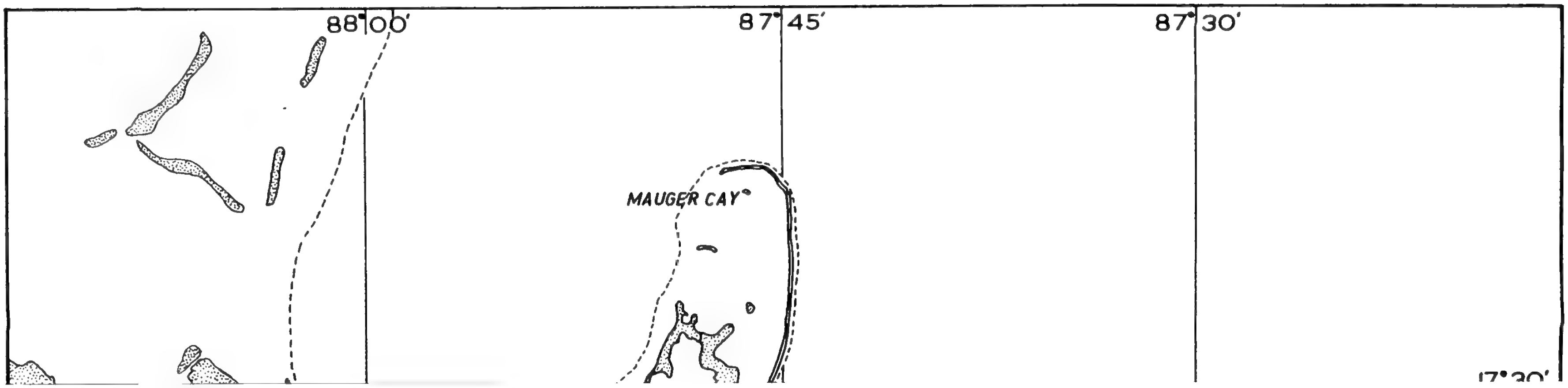


FIGURE 1
ORIGINAL SURVEY OF THE ATOLLS

FROM OWENS MANUSCRIPT MAP OF 1830
COORDINATES ADJUSTED



88°00'
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87°30'
MAUGER CAY
17°30'

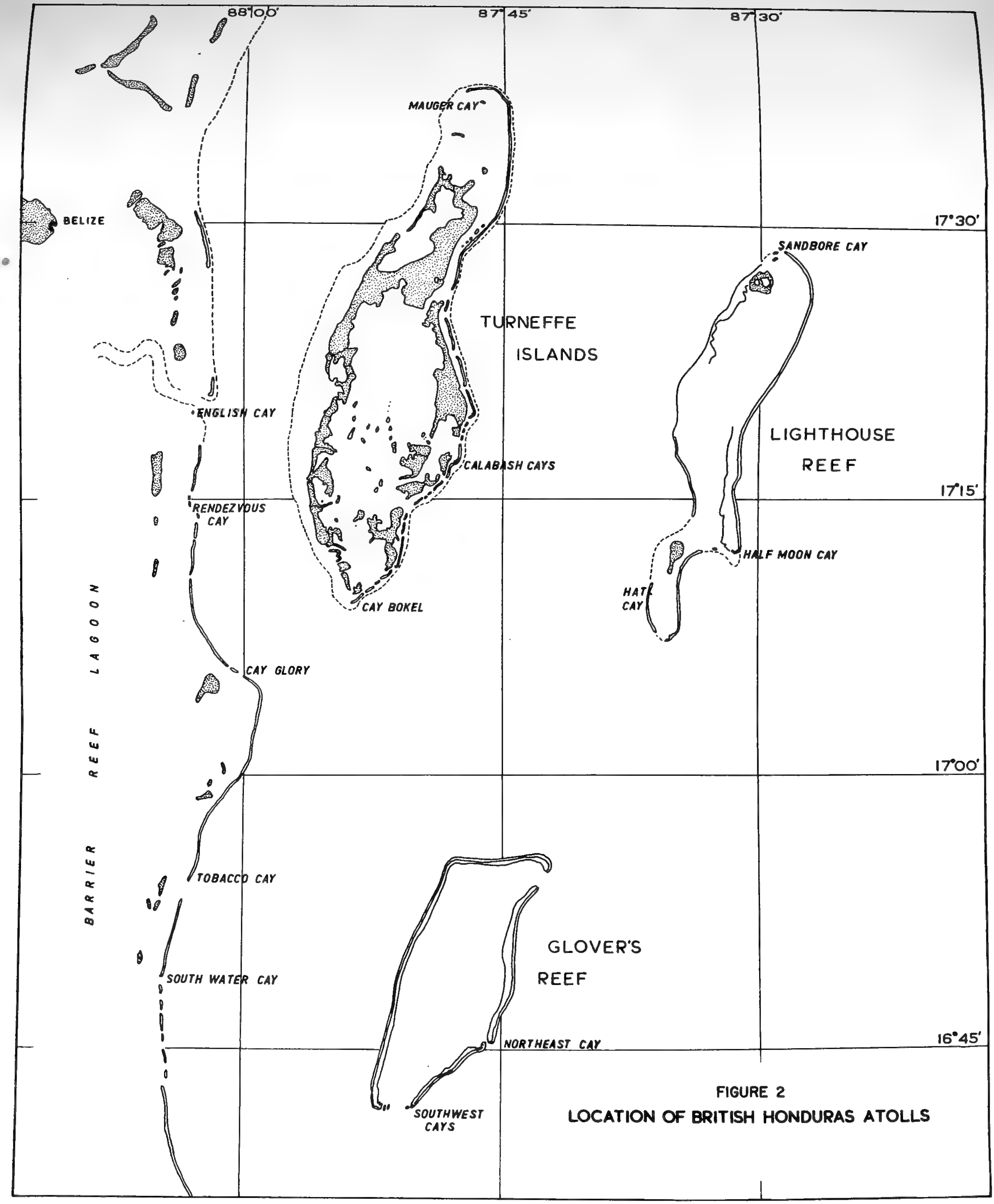
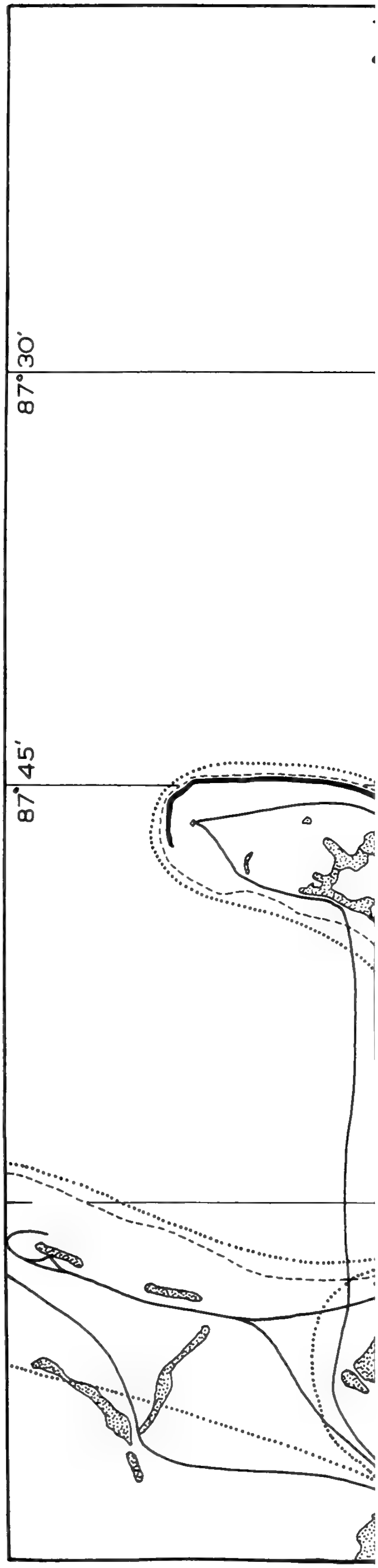


FIGURE 2
LOCATION OF BRITISH HONDURAS ATOLLS


87°30'
87°45'

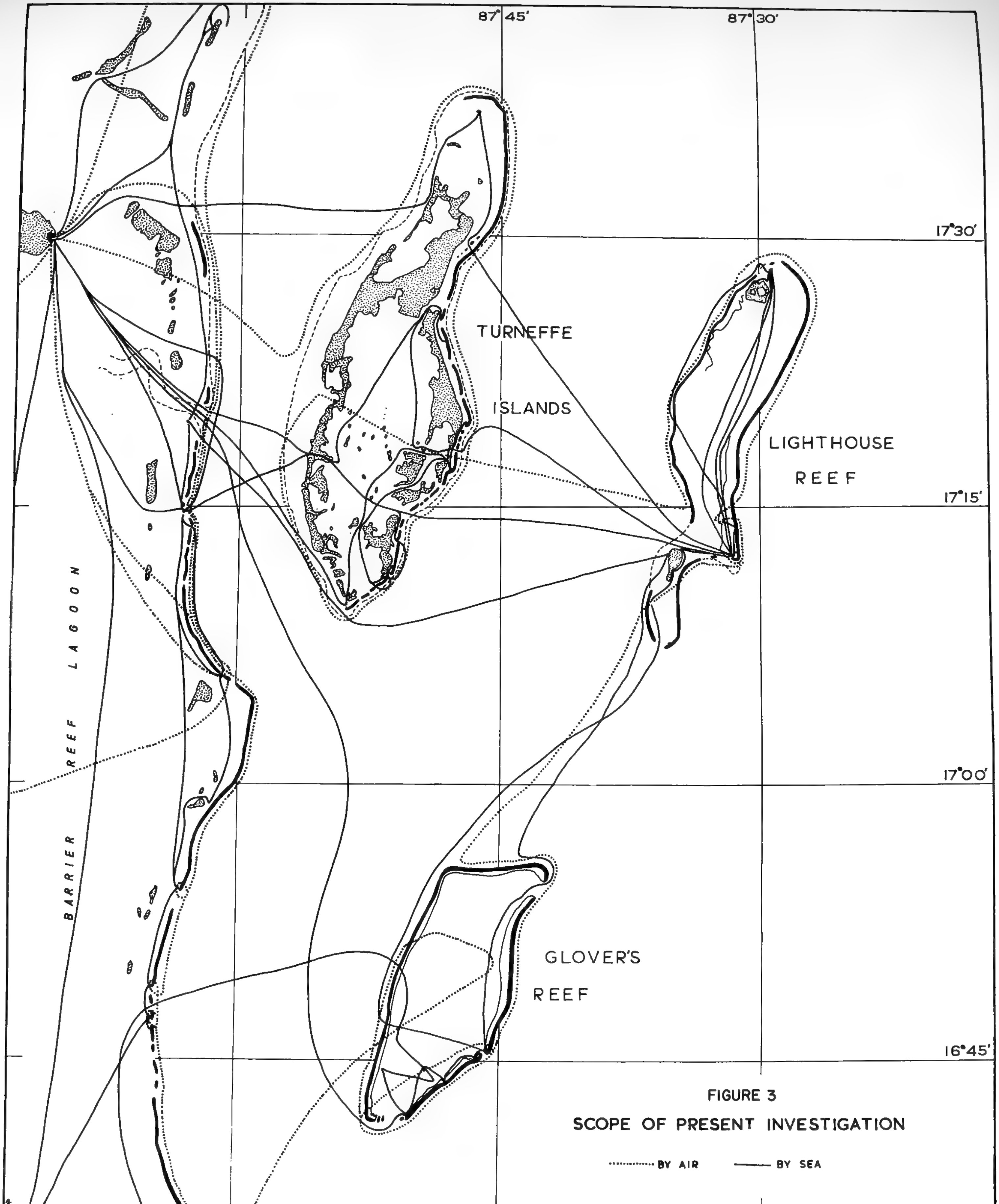


FIGURE 3
SCOPE OF PRESENT INVESTIGATION

II. GROSS FORM AND STRUCTURE OF THE OFFSHORE AREA

Submarine topography of the east coast of Yucatan

The most striking feature of the offshore topography is the marked linear orientation of surface and submarine features, and this finds some parallel in the more subdued fault-controlled lineation of drainage features in the northern limestone lowlands of British Honduras and adjacent Quintana Roo (Sapper 1899). Each of the four atolls near the base of the Yucatan Peninsula—Banco Chinchorro, Turneffe Islands, Lighthouse Reef and Glover's Reef— is aligned with its long axis trending NNE-SSW, and this is true also of Cozumel Island and the submerged Arrowsmith Bank farther north on the same coast. Available soundings are rather sparse in the area between the banks and the barrier reef, but they are sufficient to show that these apparent surface lineations are only the superficial expression of major submarine topographic features on a greater scale than any land relief on the adjacent coastlands. Figure 4 is a compilation map showing submarine contours, based on maps of the Quintana Roo coast published by Edwards (1957 and of British Honduras by Vermeer (1959). It is possible to disagree with many of the details of this map, but the gross pattern revealed is probably correct.

The whole of the east coast is bordered by two "platforms": an "upper platform" with its outer edge at approximately 2400 feet (400 fathoms), and a "lower platform", with its outer edge at approximately 6,000 feet (1,000 fathoms). A third platform, the coastal shelf, may be traced north of the Yucatan Peninsula, as a vast shallow extension of the Yucatan limestone lowland, and also in the southeast of the peninsula, off the British Honduras coast, where it is fringed by the barrier reef. Arrowsmith Bank, Cozumel Island and Turneffe are located on the edge of the "upper platform", and Banco Chinchorro rises from a spur extending eastwards from the main shelf at about the same height. No banks rise from the "lower platform" except in the south, where it supports Lighthouse Reef and Glover's Reef. In this southern section the two platforms come together, and off the southern barrier reef of British Honduras there is a single fall from sea-level to over 6000 feet depth.

Several escarpments, forming part of this "upper platform-lower platform" system may be traced off the atolls of British Honduras. For convenience, they are named here the Outer Escarpment, Turneffe Escarpment, Chetumal Escarpment, and Chinchorro Escarpment.

The Outer Escarpment extends along the southern barrier reef from Sapodilla Cays to Gladden Spit, and thence northeastwards along the east sides of Glover's and Lighthouse Reefs. Off the barrier reef the scarp is straight and steep: within $3\frac{1}{2}$ miles of Ranguana Entrance the sea floor lies at a depth of 4800 feet. Twelve soundings along this section of the barrier reef, 2-4 miles seaward from it, average 4020 feet. North of Gladden Spit the soundings off the barrier reef decrease considerably, indicating the presence of a shelf or col between Gladden Spit and Glover's Reef at depths of 900-1100 feet. The scarp crest in fact continues along the east side of Glover's Reef, giving depths of 1800-3300

feet within 1-2 miles of the reef-edge, and along the east side of Lighthouse Reef, giving depths of 6600 feet within 3 miles of the reef-edge. Between the barrier and Glover's Reef, and between Glover's and Lighthouse Reefs, the sea is less than 1,000 feet deep. Clearly, the barrier reef and the two atolls lie on the crest of a submarine scarp trending NE-SW, and at least 120 miles long. The average gradient of the scarp slope is between 1 in 3 and 1 in 4.

The "upper platform" between Glover's Reef and the barrier reef lies at a depth of 900-1100 feet. It appears to deepen northeastwards, and to pass into a pronounced trough extending in a northeasterly direction between Turneffe and Lighthouse Reef. Between the barrier and Turneffe, on the other hand, the "upper platform" continues northwards at depths of 900-1,000 feet, forming a channel 6-10 miles wide. Soundings between Turneffe and Lighthouse Reef are very meagre, but it seems that the east side of Turneffe is bounded by a submarine slope similar to that bounding the east sides of Glover's and Lighthouse Reefs, but on a smaller scale. Twelve soundings $1\frac{1}{2}$-4 miles from the west reefs of Lighthouse Reef average over 3,000 feet; a single sounding midway between Mauger Cay (north Turneffe) and Sandbore Cay (north Lighthouse Reef) is charted as 6090 feet. There is only one sounding off the east reefs of Turneffe (2 miles west of the northeast corner), of 2220 feet. It thus appears that the Turneffe Escarpment overlooks a basin with maximum depths of 6,000 feet, shoaling southwards, and passing northwards into the "lower platform". Lighthouse Reef seems to be situated on a long narrow spur, bounded on the west side by this basin, and on the east by the Outer Escarpment.

North of Turneffe and Lighthouse Reef there are no banks rising to the surface for over 60 miles. The sea floor falls regularly from the barrier and fringing reefs of the Yucatan coast to depths of up to 300 feet within 5 miles of the coast. There are no detailed charts for the east coast of Yucatan north of Belize, but it is probable that this coast too is bounded by an escarpment (Chetumal Escarpment), gentler than the others, controlling the linear nature of the coast and reefs northwards at least as far as Bahia del Espiritu Santo, where it is intersected by transverse faults from the west.

Chinchorro Bank is also bounded on the east side by a steep slope (Chinchorro Escarpment), and the same is true of Cozumel Island and Arrowsmith Bank.

Fault origin of the escarpments

The presence of these steep submarine gradients was noticed by Ower, who attributed them to offshore faulting and published a map of the southern reef area (1928, 497) showing two sets of submarine fault-lines. One set, aligned NNE-SSW, with downthrow to the southeast, corresponded to the "Outer Escarpment" delimiting the southern barrier reef and Glover's Reef, and to the "Turneffe Escarpment". These were deduced from soundings on charts, and Ower recognised the gross similarity in direction and downthrow with the faults of the northern lowlands of British Honduras.

A second set of faults was recognised transverse to the first (striking E-W and SE-NW), with downthrow to north or south. The main dryland analogy to this system which he mapped is the E-W Northern Boundary Fault of the Maya Mountains, a horst of Paleozoic rocks surrounded on all sides by Mesozoic and Tertiary limestones and other rocks. In the offshore area, the location of the transverse faults shown on Ower's map seems purely conjectural, with little relation to bottom topography; they seem to have been inserted to explain the rise of the outer atolls from their respective scarp-crests. Study of Admiralty charts in 1959 led to the conclusion that there is in fact one major set of faults controlling submarine topography, trending NNE-SSW, and giving rise to the Outer Escarpment, Turneffe Escarpment, and probably also the Chetumal and Chinchorro Escarpments (Stoddart, 1960). It was subsequently found that this interpretation had been worked out in detail by Edwards for Quintana Roo (1957) and by Vermeer for the coast of British Honduras (1959, 20-25). No other interpretation for the submarine topography seems possible with present knowledge. It is unlikely that the escarpments are constructional reef forms for several reasons. Thus the Outer Escarpment can be traced not only along modern reefs, but occurs as a submerged feature, not rimmed with reef, between the two outer atolls, and this same scarp also bounds the coastal shelf south of the southern end of the barrier reef, where it again lacks a reef-rim. Further, the Chetumal Escarpment seems to delimit for over 200 miles a coast built of non-reef limestones, along which the barrier reef is weakly and discontinuously developed, and this indicates that the reef itself is of minor importance in determining present bottom topography.

The picture which emerges, therefore, is one of a number of NNE-SSW fault-lines, arranged en echelon along the British Honduras coast, giving rise to major submarine escarpments, with average gradients of 1 in 3 to 1 in 5. The maximum gradient charted appears to be a fall in depth of over 1 mile in a distance of two miles from the surface reef, on the east side of Lighthouse Reef. The atolls are seen to be oval-shaped reefs, 13-35 miles long, rising several hundred feet above the surface of the fault-bounded platform on whose edge they stand. The offshore topography consists of a number of submarine steps, each bounded by an east-facing escarpment, each bearing at some place along its crest a reef-mass rising to sea-level (fig. 5).

Submarine scarps and regional tectonics

If the submarine topography of the northern Caribbean basin (Parr's "Cayman Sea") is viewed as a whole, the faulting deduced from chart evidence becomes comprehensible. The dominant feature of the basin is the Bartlett Trough (fig. 6) or Cayman Deep, a narrow trench extending across it for nearly 1,000 miles. The northern rim of the trough may be traced in the faulted Sierra Maestra of Southern Cuba, through the Cayman and Misteriosa Banks, and probably into the Maya Mountains of southern British Honduras (Taber, 1928; Matley, 1924). The southern rim of the trough is formed by the island of Jamaica, the Pedro, Rosalind and Nicaraguan Banks, and the mountains of the Republic of Honduras. The Trough reaches a maximum depth of over 23,000 feet. It appears to pass westwards into the Lake Izabal-Rio Dulce lowlands of Guatemala, and according to Walper (1960) may be followed as a fracture zone into the Alta Verapaz.

Dixon gives grounds for believing that movement was initiated along the Bartlett axis in pre-Cretaceous times, but the maximum dislocation took place in the late Tertiary, probably reaching a peak in the Pliocene (Schuchert, 1935). The extensive raised reefs, elevated shore terraces, and Plio-Pleistocene marine deposits of Cuba (Agassiz, 1894; Taber, 1934) and to a lesser extent Jamaica, indicate that movement on a large scale continued into the Pleistocene and may still be continuing. Little detailed work on the tectonic history of the Trough has been done since Taber (1922, 1931) outlined its main features, though recently it has been suggested that rather than being a simple normal rift, the Bartlett axis is a major zone of wrench- or transcurrent-faulting, along which considerable lateral movement occurred (Moody and Hill, 1956; Hess and Maxwell, 1953).

The reef-capped coastal features of British Honduras can thus be seen in a wider context as relatively minor dislocations along the north side of the Trough, where it abuts against the Central American mainland. Vertical movements of thousands of feet have taken place along this zone of weakness since late-Tertiary times (Schuchert, 1935), and the British Honduras faulting may have taken place in Pliocene times, even continuing into the early Pleistocene. This sets a very approximate limit to the age of the coastal reef formations. The rocks involved in the fracturing are not known, since no solid rocks outcrop anywhere on the atolls. They may have been Cretaceous-Eocene limestones similar to those blanketing the western part of the Maya Mountains, and which in northern British Honduras were subjected to dislocations of similar trend to those of the offshore areas. This layer of limestones probably overlies Paleozoic rocks at an unknown depth. Whether the main body of each atoll above the platform on which it rests consists of reef limestones or of older limestones (as Ower's suggested transverse faults may indicate) remains one of the many problems associated with these reefs.

Growing interest of oil companies in the offshore area will probably add greatly to our knowledge of the structure of the coast and reefs, through seismic exploration and deep borings.

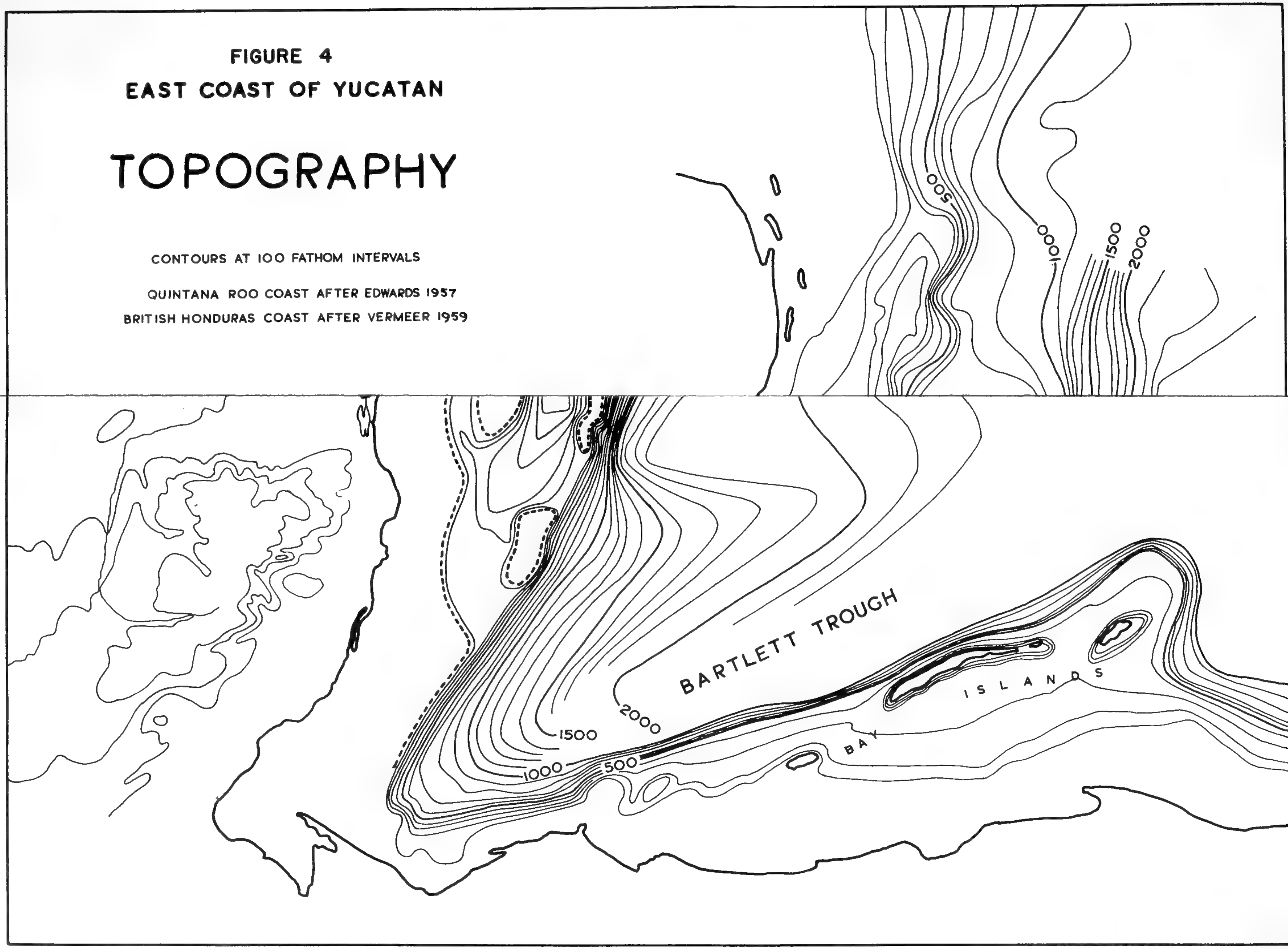


FIGURE 4
EAST COAST OF YUCATAN
TOPOGRAPHY
CONTOURS AT 100 FATHOM INTERVALS
QUINTANA ROO COAST AFTER EDWARDS 1957
BRITISH HONDURAS COAST AFTER VERMEER 1959
500
1000
1500
2000
BARTLETT TROUGH
ISLANDS
BAY
2000
1500
1000
500

FIGURE 4
EAST COAST OF YUCATAN

TOPOGRAPHY

CONTOURS AT 100 FATHOM INTERVALS

QUINTANA ROO COAST AFTER EDWARDS 1957

BRITISH HONDURAS COAST AFTER VERMEER 1959

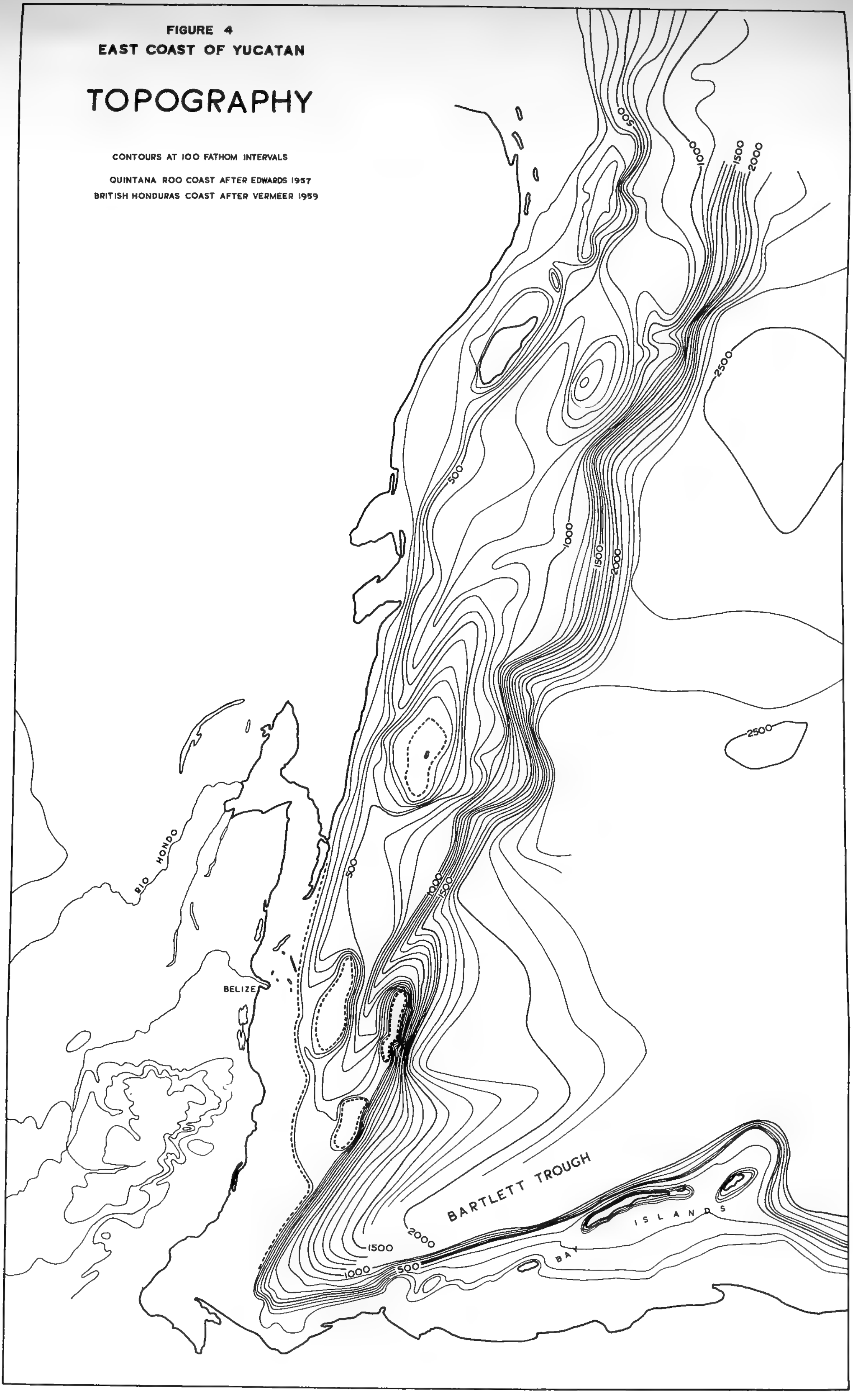


FIGURE 5

EAST COAST OF YUCATAN

STRUCTURE

GEOLOGY

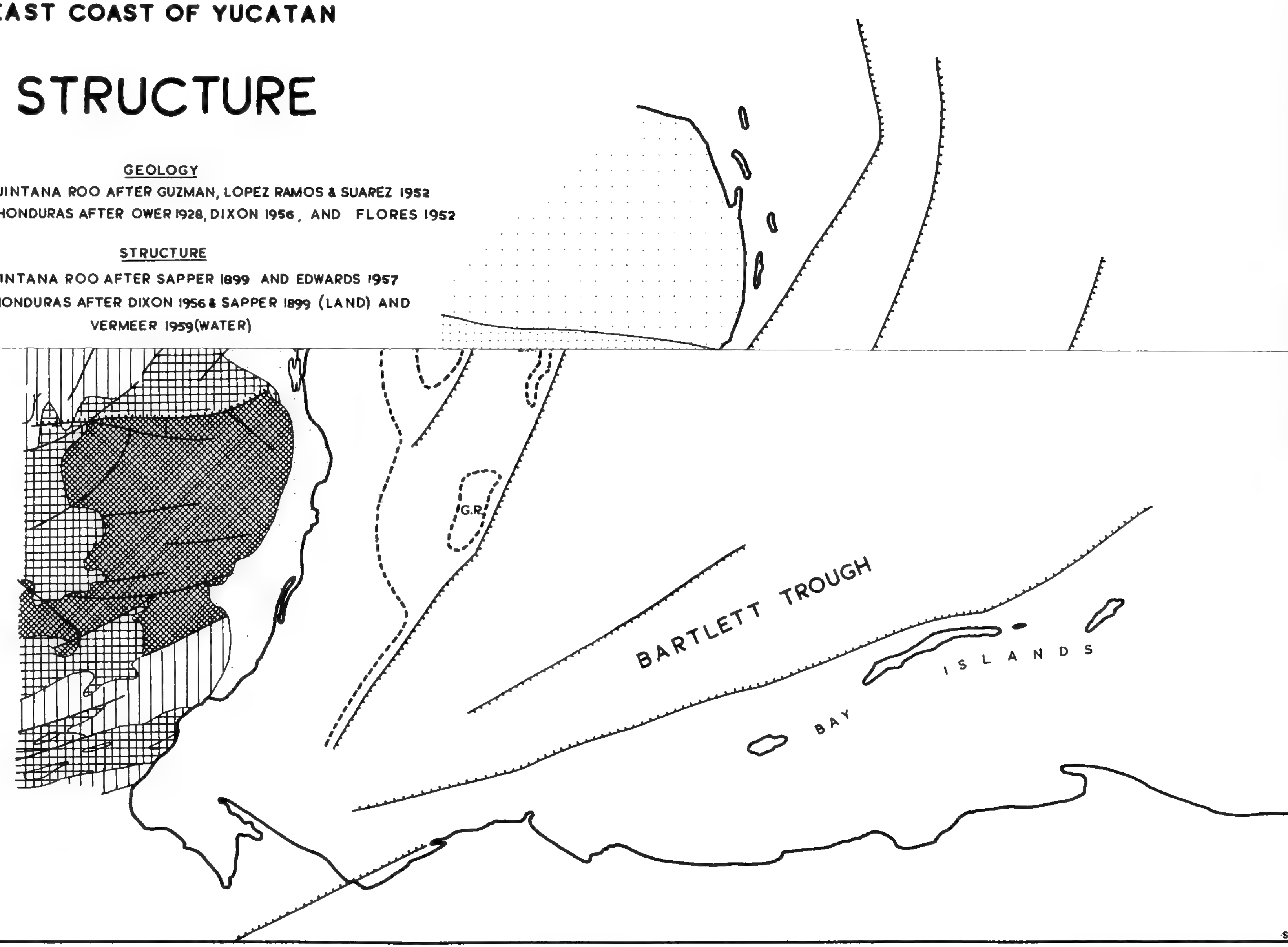
QUINTANA ROO AFTER GUZMAN, LOPEZ RAMOS & SUAREZ 1952

BRITISH HONDURAS AFTER OWER 1928, DIXON 1956, AND FLORES 1952

STRUCTURE

QUINTANA ROO AFTER SAPPER 1899 AND EDWARDS 1957

BRITISH HONDURAS AFTER DIXON 1956 & SAPPER 1899 (LAND) AND VERMEER 1959 (WATER)



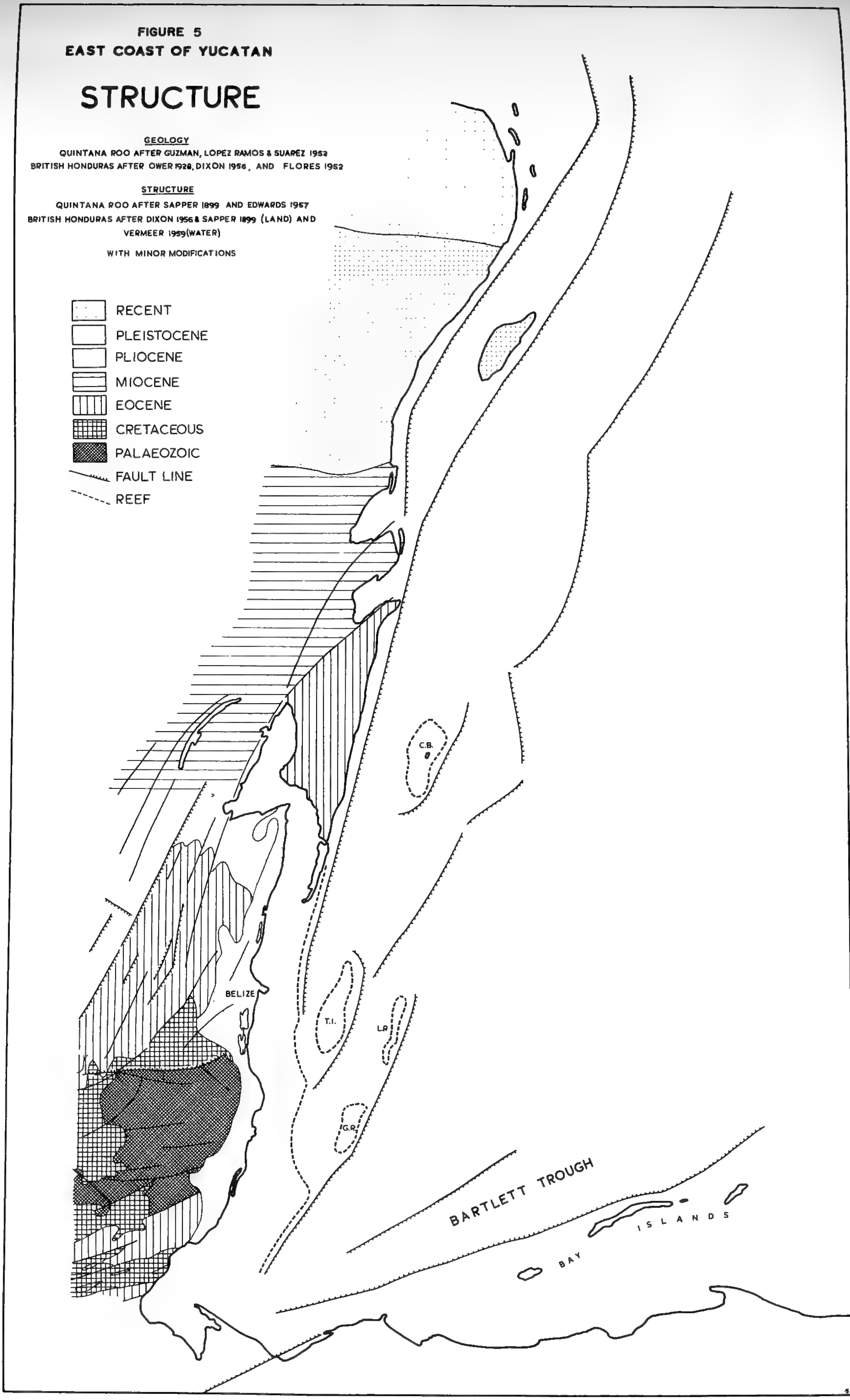
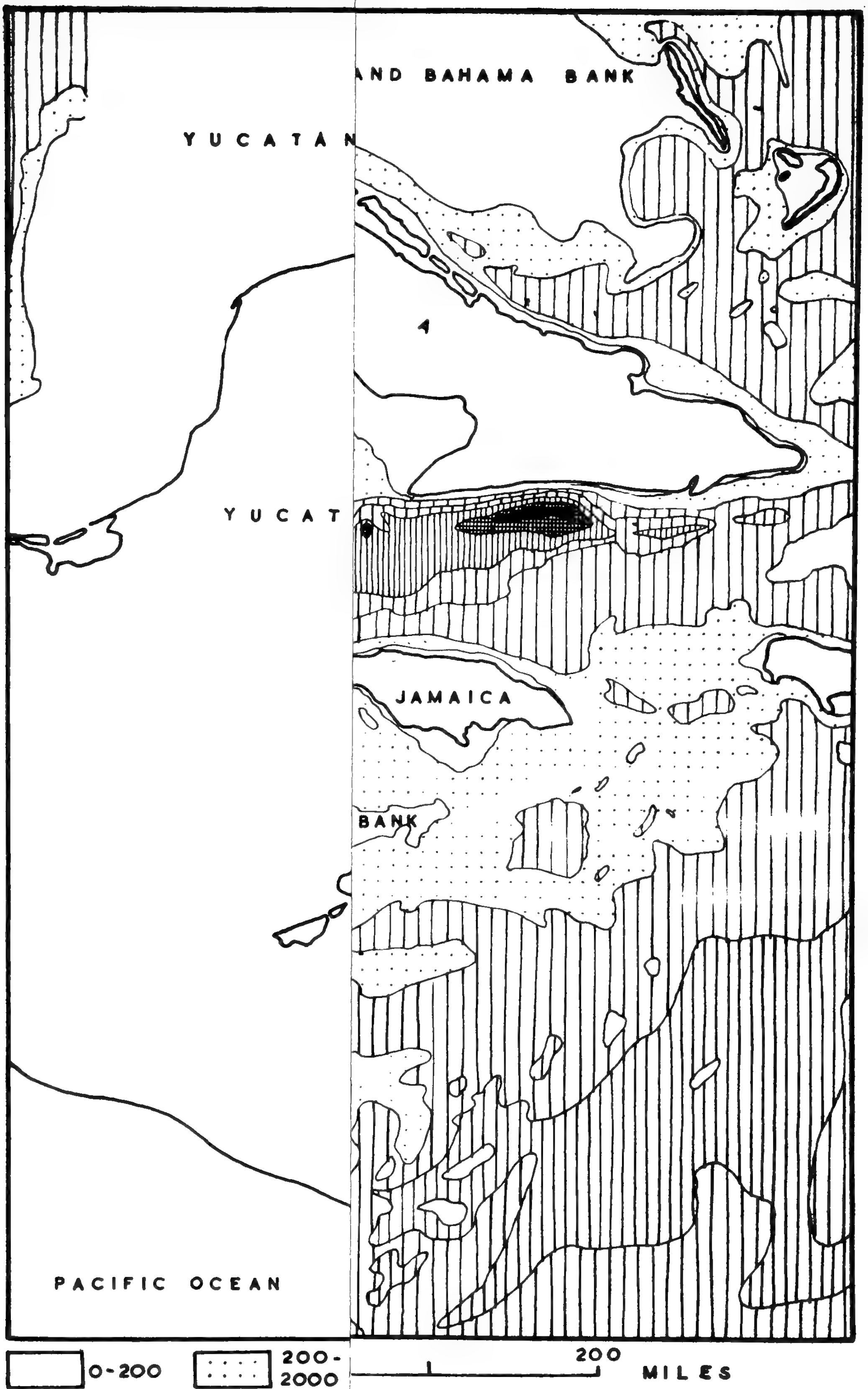
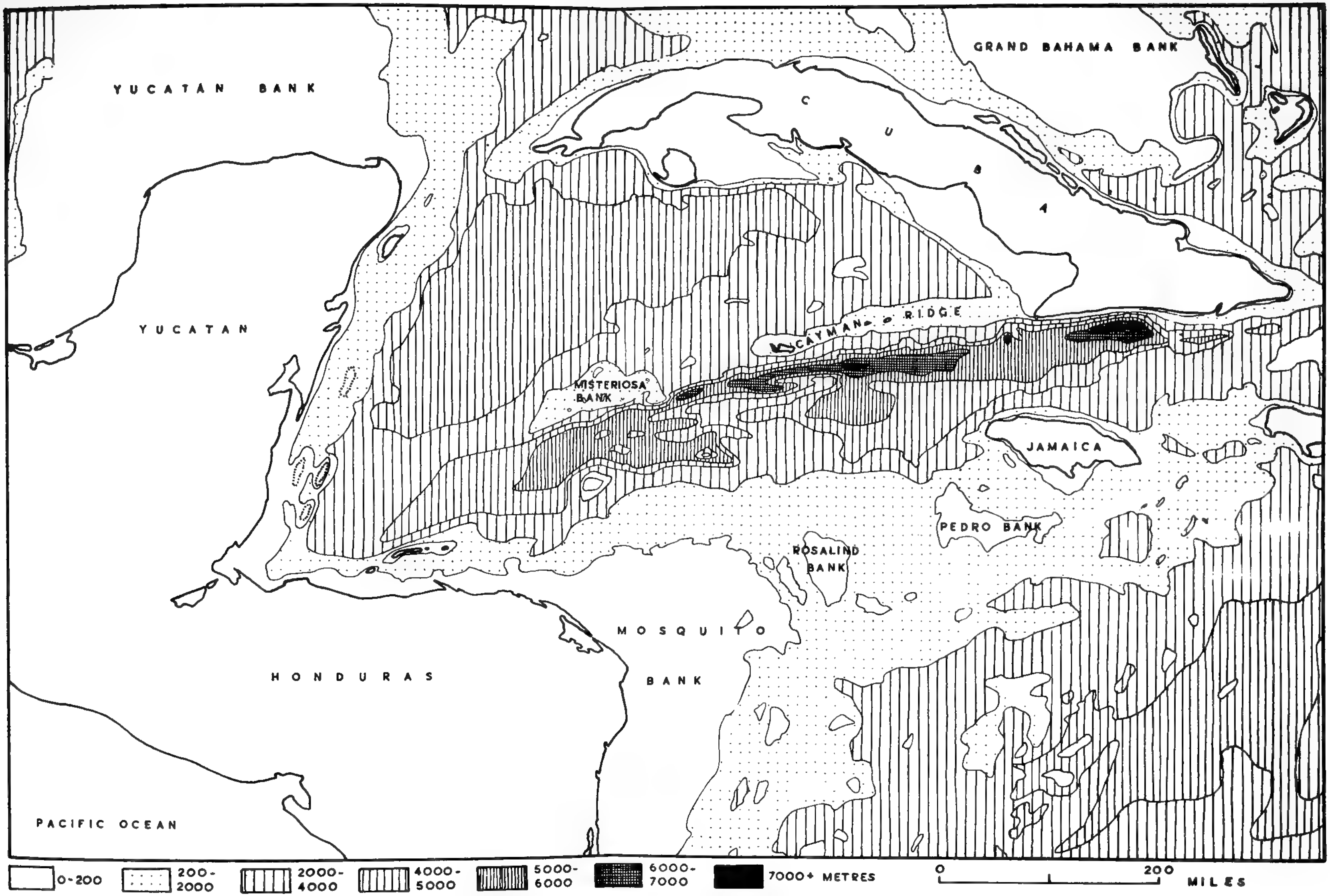


FIGURE 5
EAST COAST OF YUCATAN
STRUCTURE
GEOLOGY
QUINTANA ROO AFTER GUZMAN, LOPEZ RAMOS & SUAREZ 1952
BRITISH HONDURAS AFTER OWER 1928, DIXON 1956, AND FLORES 1952
STRUCTURE
QUINTANA ROO AFTER SAPPER 1899 AND EDWARDS 1957
BRITISH HONDURAS AFTER DIXON 1956 & SAPPER 1899 (LAND) AND VERMEER 1959 (WATER)
WITH MINOR MODIFICATIONS
RECENT
PLEISTOCENE
PLIOCENE
MIOCENE
EOCENE
CRETACEOUS
PALAEOZOIC
FAULT LINE
REEF
C.B.
BELIZE
T.I.
L.R.
G.R.
BARTLETT TROUGH
BAY ISLANDS


AND BAHAMA BANK
YUCATAN
YUCAT
JAMAICA
BANK
PACIFIC OCEAN
0-200
200-2000
200
MILES



THE BARTLETT TROUGH
FIGURE 6

III. CLIMATE, SEA CURRENTS, TIDES

In this section several factors of the environment of the atolls will be discussed, but it must be borne in mind that records have never been kept on any of them for more than very restricted periods, in spite of permanently maintained lighthouse stations on Turneffe and Lighthouse Reef, and that for statistics we must rely on data from coastal stations. With the exception of the work of Parr in the Gulf of Honduras generally, and of University of Texas workers on the British Honduras coastal shelf, there do not appear to have been any marine surveys by oceanographic vessels near the atolls.

Climate

An account of the climate of British Honduras is given by Romney and others (1959, 15-22), and of Yucatan by Page (1933, 409-422), Edwards (1957, 61), and briefly by Trewartha (1961, 70-71). Even on mainland stations data are grossly inadequate: in Quintana Roo only 2 stations have records of 20 years or more, while of all recording stations in British Honduras, only 2 record more than daily rainfall.

Taking the Yucatan peninsula as a whole, rainfall increases from north to south, and is greater along the east coast than in the interior, as shown by the following figures:

Progreso	19	inches
Merida	36	
Valladolid	47	
Cozumel	66.6	
Chetumal	49.5	
Corozal	51.9	
Belize	69.6	
Stann Creek	117.3	
Punta Gorda	166.85	

Turneffe and Lighthouse Reef lie between the latitudes of Belize and Stann Creek. By analogy with coastal conditions rainfall on the atolls should be between 70 and 120 inches; it is, however, unlikely to be so high. The atolls are low, the land area small, and the dry season long, so that the rainfall probably does not exceed an average of 70 inches for any atoll. The dry season extends from March to the end of May, and can lead to severe water shortage on the cays, which rely on rainwater butts rather than groundwater for their supply. The seasonal pattern of rainfall at Belize, which is probably comparable to the atolls, is as follows (1941-1950, Romney and others, 1959, 16):

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Inches:	3.9	2.7	1.4	2.2	3.4	6.6	5.7	7.3	9.8	9.4	8.9	8.2	69.6

The only rainfall figures available for the atolls are those quoted by Smith (1941) for Calabash Cays, east side of Turneffe, for the summer months of 1937-1939; the variability is considerable:

	April	May	June	July	Total
1937	3.46	3.47	3.50	11.52	21.95
1938	3.10	2.18	4.64	2.00	11.92
1939	0.30	0.45	1.16	2.87*	4.78

(* - Man of War Cay; no data for Calabash Cays)

The winds in the atoll area blow steadily from the east for most of the year. At Belize, the only recording station, for the period 1917-1949, 56% of winds at 0600 hours came from the E and SE quadrants and 23% from the NW (means for the year); while at 1800 hours, 75% of winds came from the E and NE quadrants. The wind data, taken from the West Indies Pilot (I, 1956, 76) are summarised in the wind roses in figures 7-9. The importance of northwest winds in early morning reflects the importance of land-and-sea breezes at a coastal location; the extent of these offshore winds is very restricted, and may not even reach the barrier reef. They are probably negligible on the atolls. The constancy of the easterlies at Belize during the summer needs no stressing: at 1800 hours in June, July and August 100% of the observed winds come from the NE, E, and SE quadrants, the two former greatly predominating.

Two further features may be mentioned in connection with winds. The first and most important is the extension of the North American high pressure system southwards during the period November-February, occasionally extending to the end of March. This brings north winds, a sudden fall of 5-7° (and sometimes much more) in air temperature, low clouds, and frequently rain and stormy weather. The whole lasts for four or five days at a time, and is known as a "norther". These are felt on the atolls as much as at Belize. Secondly, there is some evidence in the lower part of the Gulf of Honduras, in the Punta Gorda-Puerto Barrios area, and along the southern barrier reef, of occasional strong southerly winds displacing the easterlies. There is no evidence, however, that these extend to the atolls.

During the months July to October the British Honduras coast is liable to tropical hurricanes, moving westwards from the Caribbean Sea. On occasion these are highly destructive: Belize has been destroyed more than once, most seriously in 1931 (Cain 1933), while Hurricane "Janet" did great damage to Corozal and Chetumal in 1955 (Pagney 1957). Poey (1855) records major hurricanes at Belize in 1787, 1813, 1827, and 1831; the most important since then have been in 1931, 1942, 1945 (Toledo District), and 1955. The most recent have been Hurricane "Abby" in 1960, and Hurricane "Anna" in July 1961, which we witnessed at sea near Placencia, examining the damage along the mainland coast shortly afterwards. Many hurricanes have decreased in intensity by the time they have reached this coast, though during the 1955 hurricane the Chetumal anemometer broke at 150 mph. The effect of hurricanes is three-fold: the direct effect of wind in uprooting vegetation, especially coconuts; the local rise of sea-level, often of several feet, under the influence of winds and decreased atmospheric pressure; and the action of wind-generated

waves in eroding and redepositing bottom material and often damaging the living reef (Moorhouse 1936; Blumenstock 1958a, 1958b, 1961; McKee 1959). The immediate physiographic effects on low land areas are considerable: deposition of rubble and fresh sand carpets, building of shingle ridges, and erosion of former land areas, and these effects will be detailed for the British Honduras atolls in the more detailed accounts which follow. Experience on Jaluit Atoll, Marshall Islands, however, shows that some of these changes are only temporary (Blumenstock, Fosberg and Johnson 1961).

The same observation may be made for the effects of "northers." Erosion often occurs along the northern margins of cays during "northers", with the building of sand spits proceeding at the same time to leeward (often at the southwest corner); but these are shortlived features and disappear when the easterlies reassert themselves. Small sandbores even appear and disappear seasonally in response to wind direction, and a similar observation has been made by Folk on Alacran (personal communication). Not all the changes are temporary, however, at least when measured in terms of decades. Marginal attrition of cays, and the slow disappearance of storm-built ramparts are a different matter from the disappearance of a cay altogether, especially if it is vegetated. Once a vegetated cay is swept away, it is a very long time before the re-emergent sandbore becomes sufficiently stable, through colonisation by vegetation and the formation of beachrock, to become a cay once more. No example is known on the British Honduras reefs where this has happened, except at Cay Glory (Barrier Reef), which now has a mat of *Sesuvium* and *Euphorbia*, and a single small coconut tree. Yet numerous examples of cays washed away in storms are known. In this respect it may be noted that the path of maximum destruction in hurricanes is narrow, and that rarely is more than one cay seriously damaged. Thus the 1935 hurricane, which destroyed Paunch Cay and flooded St. George's Cay on the barrier reef, did no damage whatever at English Cay four miles to the south.

Little is known of the effect of hurricanes on coral formation; though it is known that globular coral colonies may be rolled across reef-flats, and, in deeper water, large tree-like colonies of *Acropora palmata* may be completely inverted even in "northers".

There are few data on air temperatures, apart from the Belize records. Average records here for 1917-1949 (*West Indies Pilot*, I, 1956, 76) are as follows:

^oF.	Mean	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily max	85	81	82	83	86	87	87	87	88	87	85	83	81
Daily min	72	68	69	71	74	75	75	75	75	74	71	67	68

Air temperatures recorded at mid-day at Rendezvous Cay, barrier reef, September 1959 to May 1960, were:

Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
89	88	80	80	80	79	80	82	82.7

Mean mid-day shade temperatures fluctuate between 80 and 89^{o}F throughout the year at Belize, falling at night to means of 67-75^o. According to

the West Indies Pilot, the means of the highest temperatures in each month, 1917-1949, range at Belize from 85° in December and January to 90° in May and August-October. The mean of the lowest temperatures in each month ranges from 57° in January to 69° in July and August. The most sudden variations in temperatures are associated with "northers": according to the Rendezvous Cay records these generally involve a sharp fall of 5-7°C lasting several days. It is worth noting that the sensible effect of such a fluctuation is much more intense for white persons accustomed to the heat than the figures might suggest, and cold can cause some discomfort on the cays in winter even though the temperature does not fall below 65°F.

Marine environment

Even less data are available on sea temperatures. The Rendezvous Cay records for September 1959 to May 1960 are as follows:

°C	Mean	Maximum	Minimum
September	29.8	30.5	28.5
October	29.9	31.1	28.5
November	28.6	29.5	27.5
December	27.1	28.0	26.0
January	27.0	28.0	26.0
February	26.4	27.0	25.5
March	26.5	28.0	25.0
April	28.0	30.5	26.0
May	28.8	29.0	28.5

The figures show a slight seasonal fluctuation in the means from 26.4°C in February to probably 30° or more in summer: the daily figures show that water temperatures remain unaffected by the sudden fall of air temperature during "northers". These temperatures are well within the optimum range for reef growth of 25-29° specified by Vaughan and Wells (1943, 55), and well above the lethal lower limit for most West Indian species of 16° (Mayer, 1915, 212).

This is of some significance in view of the great change in coral composition of the British Honduras barrier reef north of Cay Caulker, where the usual dominance of Montastrea annularis and Acropora palmata gives way to a community in which Siderastrea siderea is dominant, with some Montastrea cavernosa and numerous Gorgonians. Only one poor specimen of M. annularis was seen in a transect one mile south of San Pedro, Ambergris Cay. Vermeer noted that the reef here seemed less healthy and vigorous than the reef farther south, and suggested that this resulted from upwelling of cold water along this coast (1959, 123-4)(also H.O. Publ. No. 225). No figures are available, but certainly the water feels considerably cooler than anywhere else on the British Honduras reefs, irrespective of weather. Temperature-inhibition of reefs by upwelling was suggested by Crossland as long ago as 1902, and has subsequently been considered by Ranson (1952), Newell (1954, 1956), and Newell and others (1951). Mayer (1915, 212) showed that Siderastrea radians has a considerably lower death temperature than other West Indian corals: hence Vermeer's suggestion is certainly worth further study. It is probable

that an area of upwelling does exist off Ambergris Cay, immediately north of Turneffe, but no effects of this have been noticed on any of the atolls. In particular, upwelling effects were not noticed on the eastern sides of the atolls, in spite of a similar situation to the Ambergris coast. The reef at the north end of Turneffe is particularly well developed, with a groove-and-buttress system even extending for a short distance down the leeward side.

Upwelling certainly takes place farther north along the east Yucatan coast, as shown in temperature profiles published by Agassiz (1888b, 219) and especially Parr (1937, 37, 42, 43, 46). According to Parr's sections, the 24°C isotherm at Cape Catoche reaches within approximately 10-15 fathoms of the surface, whereas at Bahia de la Ascension 140 miles to the south it lies at 100 fathoms depth. This latter point is still 130 miles north of Ambergris Cay.

The upwelling off Quintana Roo and presumed upwelling off Ambergris Cay are associated with oceanic circulation patterns (fig. 10) in the Caribbean Sea (West Indies Pilot, I, 1956, 20-25; Parr, 1935; Vermeer, 1959, 121-3). The main Caribbean Current flowing westwards from the Lesser Antilles sets west and north from Cabo Gracias a Dios towards the Yucatan Channels. In the angle formed by the Gulf of Honduras, a counter-current is created, flowing southwards. The main current flowing northwards attains a rate of 1½-2 knots in summer, and is less powerful during the winter "northers". At this period the counter-current becomes stronger, both on the coastal shelf and round the atolls; it is said to extend as far north in winter as Banco Chinchorro. On the coastal shelf, the counter-current sets south throughout the year, and continues eastward to Truxillo and beyond. The currents round the atolls are summarised in the West Indies Pilot (I, 1956, 462, 460) as follows:

> "In the vicinity of Glover reef, Lighthouse reef, and Turneffe islands, the currents during November, December and January depend on the winds; a north-going current is experienced during westerly winds, and a south-going current during northerly winds. During February and March the currents are mainly north-going, with a rate of about 1½ knots. In April and May they are nearly south-going, with a rate of about 1½ knots. In June, July and August the currents are mainly north-going, with a rate of about 1½ knots, which increases to 2 knots during September and October."; "...a strong west-going current has been experienced on several occasions between Glover Reef and Lighthouse Reef." (see also H.O. Misc. Pub. No. 10690).

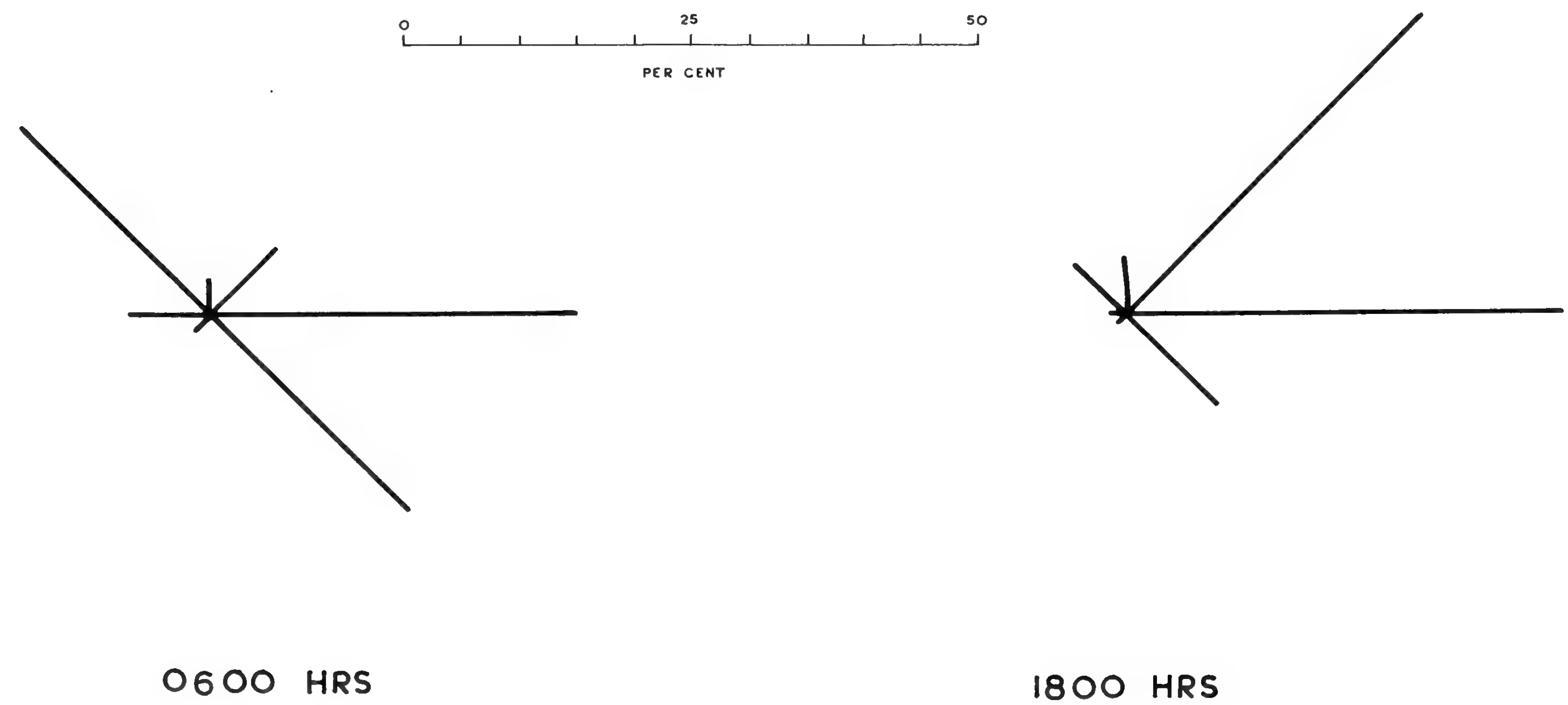
Tides are less than 2 feet throughout the area, and tides on the atolls probably average little more than a foot (Admiralty Tide Tables). More important in affecting the height of the sea surface on many occasions are the winds: north winds may depress the surface level 6 inches to 1 foot below its normal position, exposing large areas of sand, adjacent to islands, which are normally submerged, and exposing the upper parts of reef corals. Because of the small tidal range, tidal currents are not generally important, except in narrow passages between islands, especially the narrow entrances (bogues, creeks) connecting the Turneffe lagoons with the sea. These are locally sufficient to make small-boat navigation difficult against the set of tidal currents.

Even less is known of temperature and other conditions within the atoll lagoons, though there is some evidence that temperature and salinity are liable to extreme fluctuations within the enclosed Turneffe lagoons. Smith (1941) quotes surface temperatures in August 1939 within the Southern Lagoon of 29.5°-31°C. Salinity within the Southern Lagoon during June 10-20th 1939 reached 70°/oo, compared with 40°/oo at Calabash Cay on the eastern reef. By August the lagoon salinity was back to 36-38°/oo; the June high is explained by lack of rainfall and high temperatures. Measurements in 1938 at Man of War Cay (southern entrance of Southern Lagoon) averaged 37.6°/oo in June-August. These fluctuations in part at least may explain the absence of corals in the Turneffe lagoons. The lagoons of Lighthouse and Glover's Reefs, open to the sea, probably do not suffer from these extremes.

Surface temperatures measured in the Southern Lagoon, Turneffe, in June-July 1961 averaged 29°C, and in Lighthouse Reef lagoon 28.5°C.

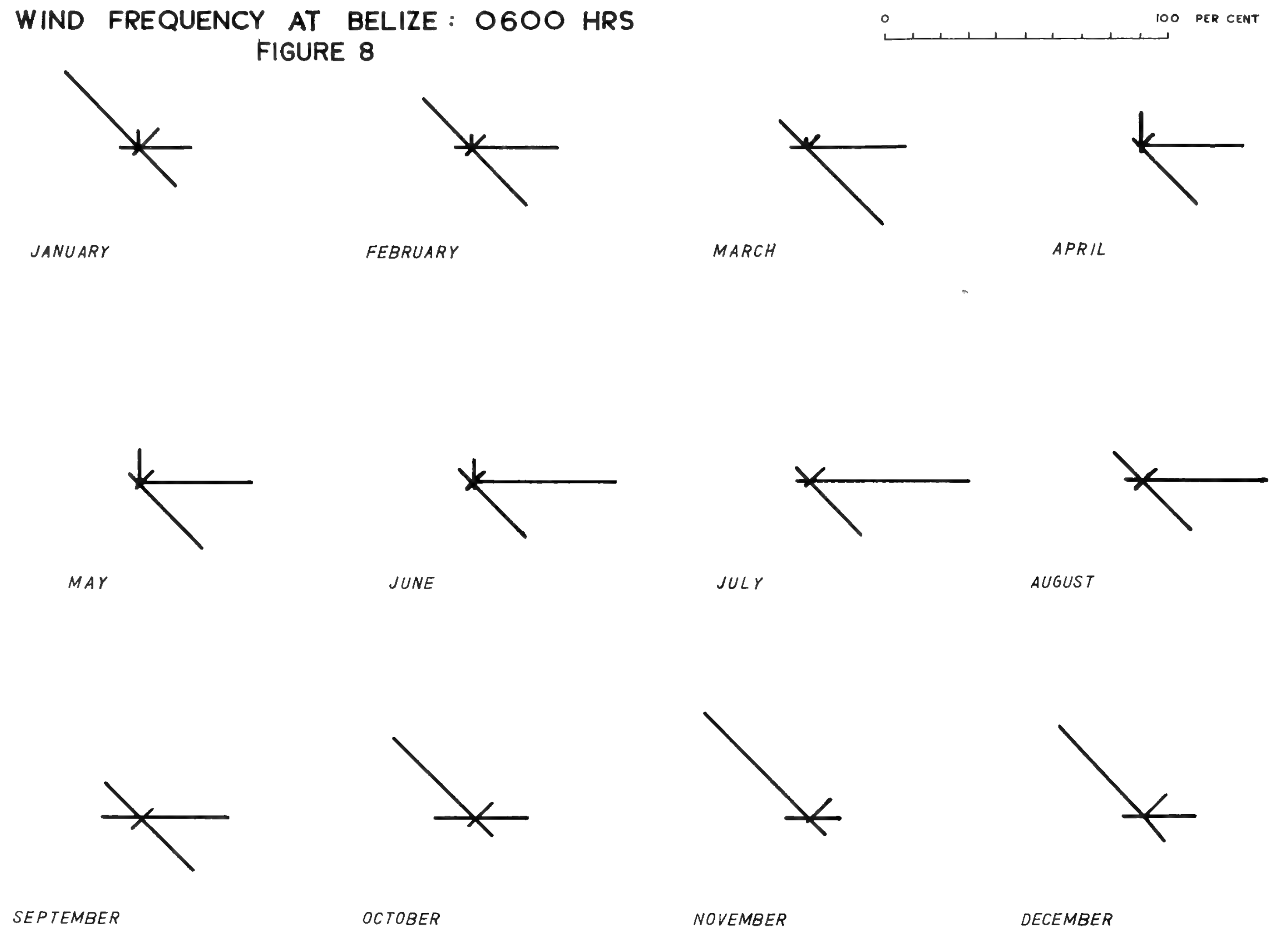
FIGURE 7

MEAN ANNUAL WIND FREQUENCY AT BELIZE



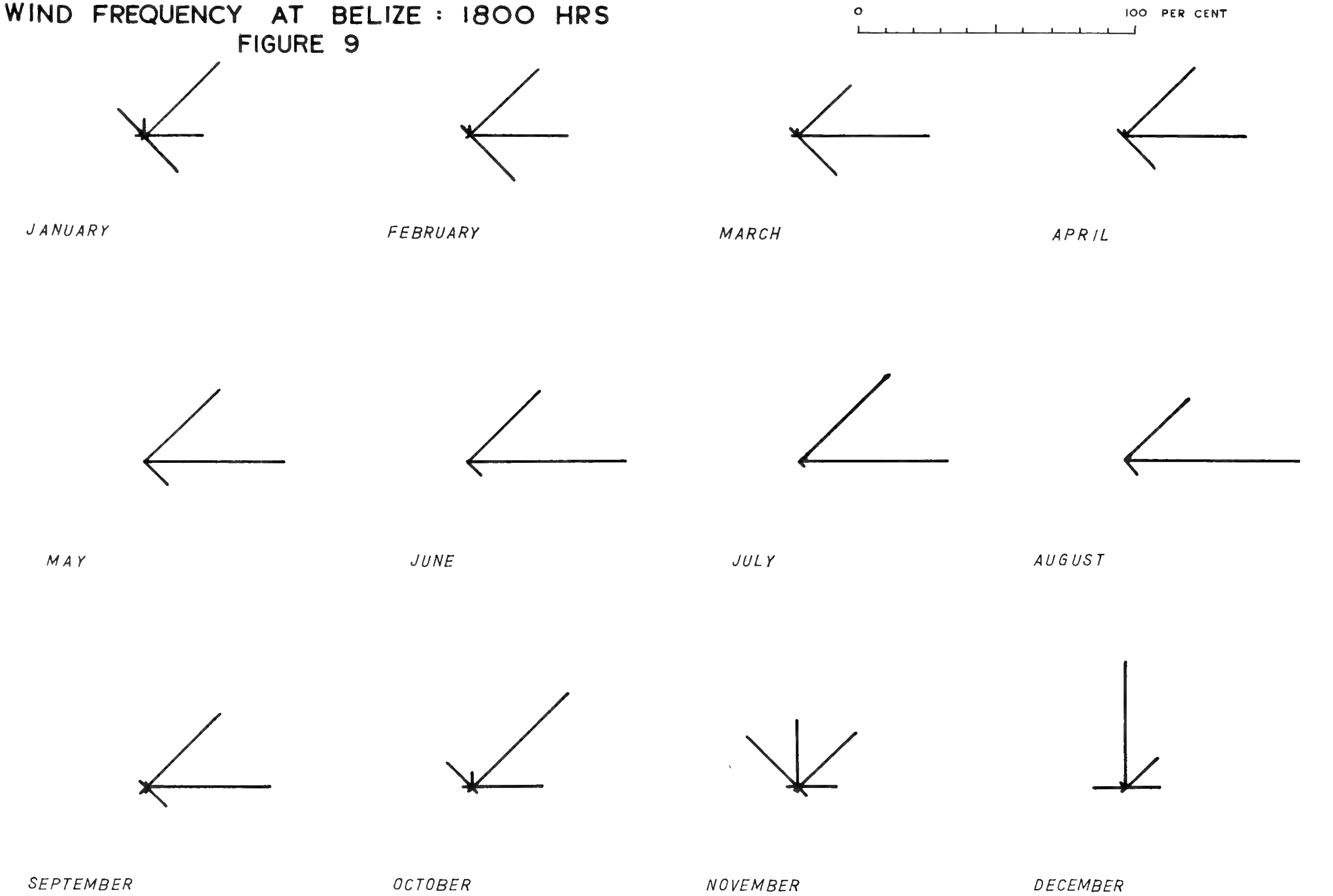
WEST INDIES PILOT, VOL. I, 1956, 76

WIND FREQUENCY AT BELIZE : 0600 HRS
FIGURE 8



WEST INDIES PILOT, VOL. I, 1956, 76

WIND FREQUENCY AT BELIZE : 1800 HRS
FIGURE 9



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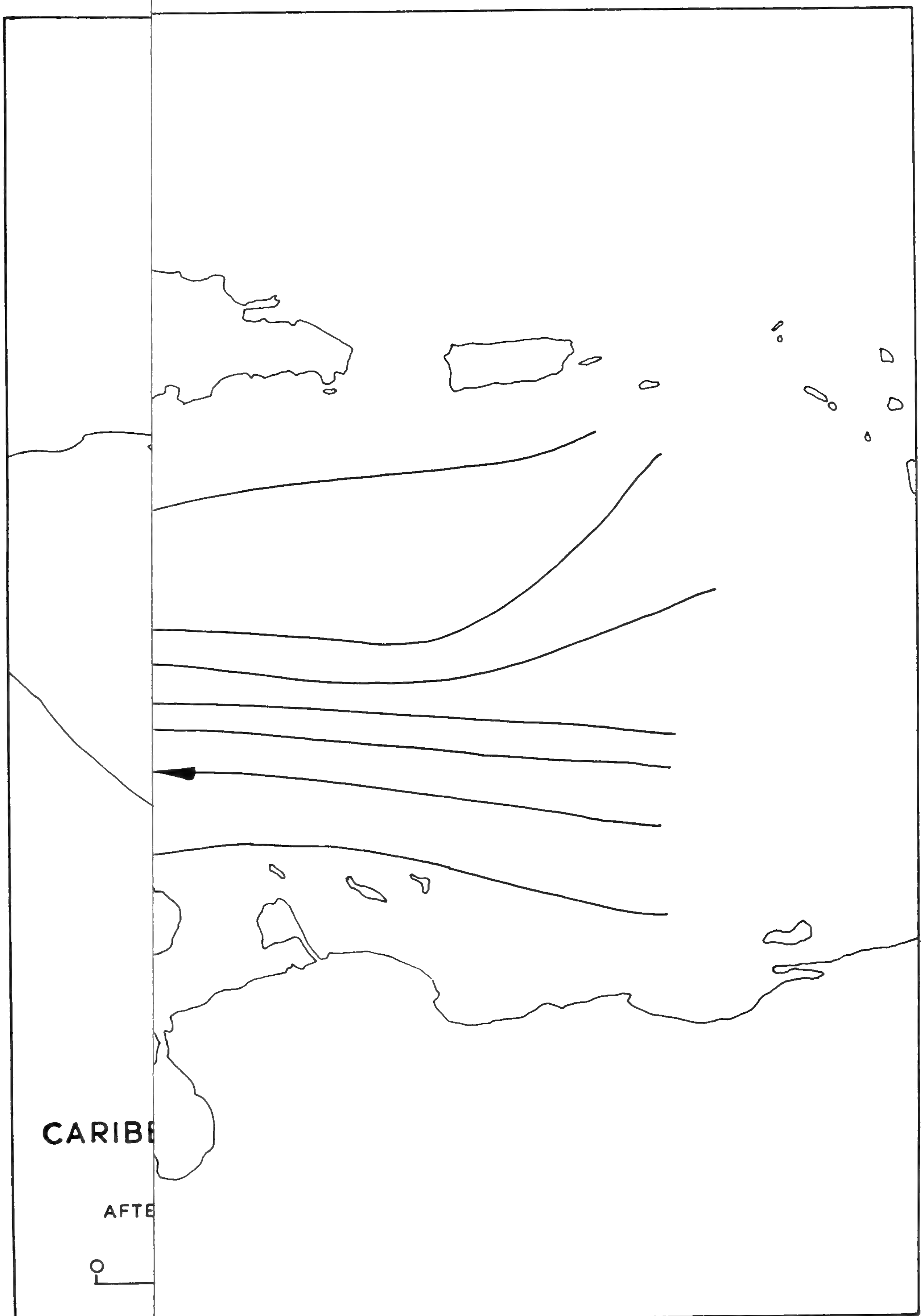

CARIBE
AFTE
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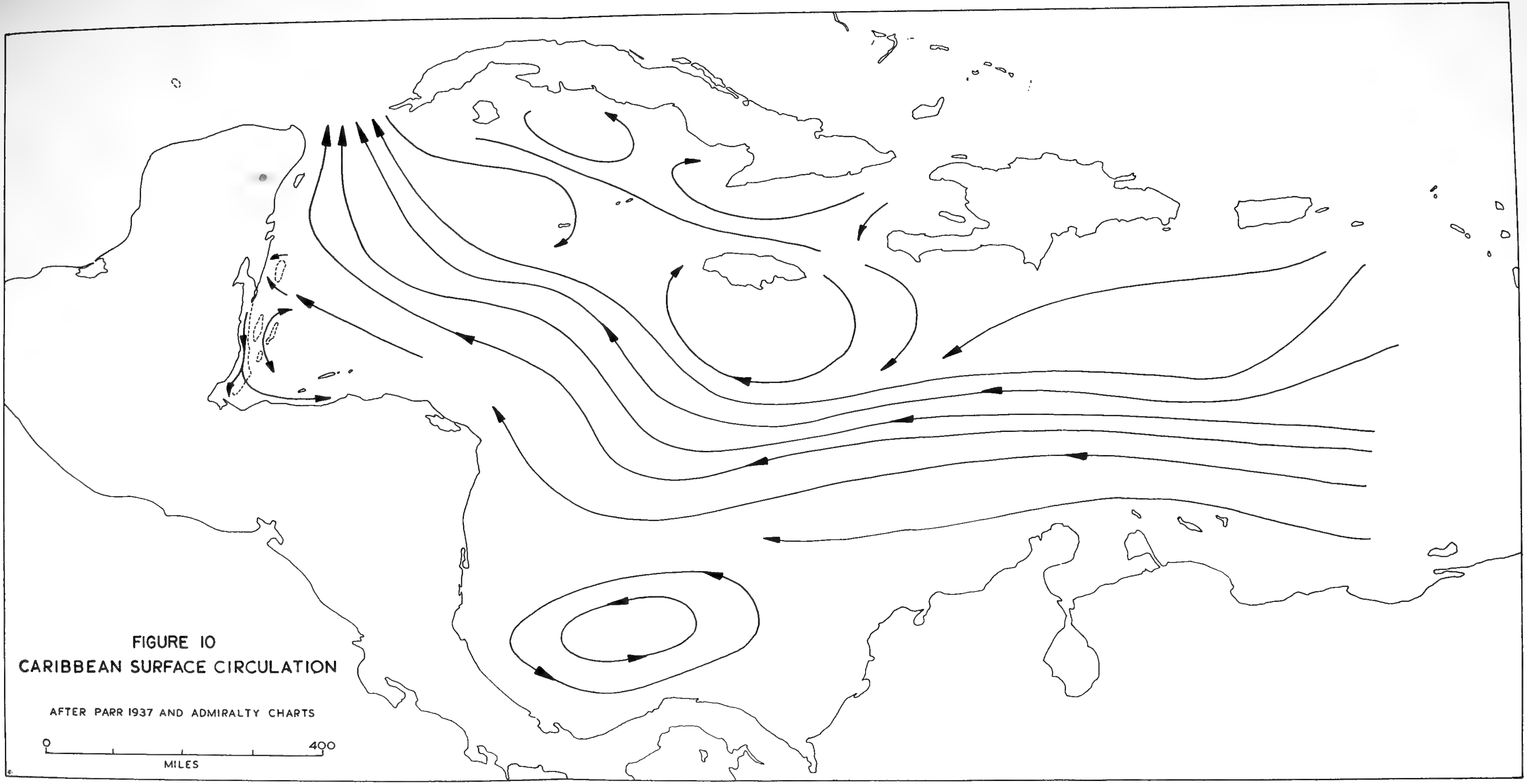


FIGURE 10
CARIBBEAN SURFACE CIRCULATION

IV. THE REEFS OF THE ATOLLS

Species-composition of the reefs

It is proposed to treat the reefs of the atolls together, rather than deal with them under the more detailed accounts of individual atolls, to avoid repetition and aid comparison. So far as is known, there are no previous descriptions of the reef fauna or ecology of any of these atolls. A preliminary account of the distribution of corals on the Rendezvous Cay reef-patch, Barrier Reef, has been given by Thorpe and Bregazzi (1960), who list the following species of stony corals. From work elsewhere on the Barrier Reef it appears that this list is representative of the fauna of the Barrier Reef in general: only *Meandrina meandrites* was not found at Rendezvous Cay, but was collected nearby.

Table 1. Corals found at Rendezvous Cay
(Thorpe and Bregazzi 1960)

Seriatoporidae:
- *Madracis decactis* Lyman

Acroporidae:
- *Acropora cervicornis* Lamarck
- *Acropora palmata* Lamarck
- *Acropora prolifera* Lamarck

Agariciidae:
- *Agaricia agaricites* Linnaeus
- *Agaricia nobilis* Verrill

Siderastreidae:
- *Siderastrea radians* Pallas
- *Siderastrea siderea* Ellis and Solander

Poritidae:
- *Porites astreoides* Lamarck
- *Porites divaricata* Lesueur
- *Porites furcata* Lamarck
- *Porites porites* Pallas

Faviidae:
- *Favia fragum* Esper
- *Diploria clivosa* Ellis and Solander
- *Diploria labyrinthiformis* Linnaeus
- *Diploria strigosa* Dana
- *Colpophyllia natans* Muller
- *Manicina areolata* Linnaeus
- *Cladocora arbuscula* Lesueur
- *Solenastrea bournoni* Milne-Edwards and Haime
- *Montastrea annularis* Ellis and Solander
- *Montastrea cavernosa* Linnaeus

Trochosmiliidae:

Meandrina meandrites Linnaeus
Dichocoenia stokesii Milne-Edwards and Haime
Dendrogyra cylindrus Ehrenberg

Mussidae:

Mussa angulosa Pallas
Isophyllastrea rigida Dana
Mycetophyllia lamarckana Milne-Edwards and Haime
Isophyllia multiflora Verrill

Caryophyllidae:

Eusmilia fastigiata Pallas

Milleporidae:

Millepora alcicornis Linnaeus
Millepora complanata Lamarck

The reef fauna of the three atolls is closely comparable with this list from the Barrier Reef, but not all the species found at Rendezvous were seen on the atoll reefs. Conversely, Meandria meandrites, which is rarely seen living on the Barrier Reef and is rarely found in the debris of shingle ridges on the Barrier Reef cays, is a prominent constituent of shingle ridges on the atolls, especially on Glover's and Lighthouse Reefs. No living colonies have been seen on the atolls, however, which suggests that it is restricted to deeper, rougher water on the seaward slopes of reefs.

The Rendezvous Cay fauna corresponds closely with that of other reef areas in the Caribbean, though the number of genera, excluding Millepora, which is 20, and species (28), is less than in Jamaica (25 and 41 respectively: Goreau 1959). Table 2 summarises species records for a number of Caribbean localities, including Alacran Reef (north of the Yucatan Peninsula) (Kornicker and others1959), Rendezvous Cay (Thorpe and Bregazzi 1960), Pedro Bank (Zans 1958), Jamaica (Zans 1959; Goreau 1959), and Bimini, Bahamas (Squires 1958). The records made in 1959-60 and 1961 at Turneffe, Glover's Reef and Lighthouse Reef are included, and though the record for these atolls is by no means complete, the most numerous and important species are probably included. Many of the gaps are undoubtedly due to omissions in collecting rather than to non-occurrence. 24 species (excluding Millepora) are common to the atolls, taken together, and Rendezvous Cay. 5 species have been recorded at Rendezvous and not on the atolls, while no species is recorded from the atolls which is not also seen at Rendezvous. The species not recorded from the atolls are all minor reef-builders: Madracis decactis, Acropora prolifera, Agaricia nobilis, Isophyllia multiflora, Cladocora arbuscula and Solenastrea bournoni. The comparison with the records from the two nearest reef areas--Alacran and Pedro Bank--is also interesting. Species recorded from the three atolls and not from Alacran include Porites divaricata, Colpophyllia natans, Meandrina meandrites, Isophyllastrea rigida, and Mycetophyllia lamarckana; Colpophyllia amaranthus is recorded from Alacran but not the atolls. Zans's records from the Pedro Bank are

Table 2

	1	2	3	4	5	6	7	8	9	10
Stephanocoenia michelini	-	-	-	-	-	-	-	x	x	x
Madracis decactis	-	-	-	x	-	-	-	-	x	-
Acropora cervicornis	-	x	x	x	x	x	x	x	x	-
Acropora palmata	x	x	x	x	x	x	x	x	x	x
Acropora prolifera	x	-	-	x	-	-	-	x	x	-
Agaricia agaricites	-	-	x	x	x	x	x	x	x	x
Agaricia fragilis	-	-	-	-	-	-	-	x	x	-
Agaricia nobilis	-	-	-	x	-	-	-	x	x	-
Siderastrea radians	?	-	x	x	x	-	-	x	x	x
Siderastrea siderea	-	x	x	x	-	x	x	x	x	x
Porites astreoides	x	-	x	x	x	x	x	x	x	x
Porites branneri	-	-	-	-	-	-	-	x	-	-
Porites divaricata	-	-	-	x	x	-	-	-	-	x
Porites furcata	x	x	x	x	-	-	x	-	-	x
Porites porites	-	-	x	x	x	x	x	-	x	x
Favia fragum	-	-	x	x	x	x	-	x	x	x
Diploria clivosa	-	x	x	x	-	-	x	x	x	x
Diploria labyrinthiformis	x	x	x	x	x	-	x	x	x	-
Diploria strigosa	x	x	x	x	x	x	x	x	x	x
Colpophyllia amaranthus	-	-	x	-	-	-	-	x	x	-
Colpophyllia natans	-	-	-	x	-	-	x	x	x	-
Manicina areolata	-	-	x	x	-	x	-	x	x	x
Cladocora arbuscula	-	-	-	x	-	-	-	-	x	-
Solenastrea bournoni	-	-	-	x	-	-	-	-	x	-
Montastrea annularis	x	x	x	x	x	x	x	x	x	x
Montastrea cavernosa	?	x	x	x	x	x	x	x	x	x
Oculina diffusa	?	-	-	-	-	-	-	x	x	x
Meandrina meandrites	-	-	-	x	x	x	x	x	x	-
Meandrina brasiliensis	-	-	-	-	-	-	-	-	x	-
Dichocoenia stokesii	-	-	-	x	-	x	-	x	x	x
Dendrogyra cylindrus	-	-	-	x	x	x	x	-	x	-
Mussa angulosa	-	-	x	x	-	-	x	x	x	-
Isophyllastrea rigida	-	-	-	x	x	x	x	x	x	x
Mycetophyllia lamarckana	-	x	-	x	x	x	x	-	x	-
Isophyllia sinuosa	-	-	-	-	-	-	-	x	x	x
Isophyllia multiflora	-	-	-	x	-	-	-	x	x	-
Eusmilia fastigiata	-	-	x	x	-	-	x	-	x	x
Millepora sp.	-	-	x	x	x	x	x	x	-	x

1. Vera Cruz (Heilprin 1890)
2. Blanquilla (Moore 1960)
3. Alacran (Kornicker and others 1959)
4. Rendezvous Cay (Thorpe and Bregazzi 1960)
5. Turneffe
6. Lighthouse Reef
7. Glover's Reef
8. Pedro Bank (Zans 1958)
9. Jamaica (Goreau 1959)
10. Bimini, Bahamas (Squires 1958)

based on boulder material from the cays only. Species recorded here and not on the atolls include Stephanocoenia michelini, Acropora prolifera, Agaricia fragilis, Agaricia nobilis, Porites branneri, Colpophyllia amaranthus, Oculina diffusa, Isophyllia sinuosa and I. multiflora. Recorded from the atolls and not from Pedro Bank are Porites porites, Porites furcata, Dendrogyra cylindrus and Mycetophyllia lamarckana.

The atoll fauna is thus typically Caribbean, and agrees in composition with Goreau's hypothesis of a species-maximum for Caribbean corals in the Jamaica-Puerto Rico-Florida-Bahamas area. Thirteen species are common to all three atolls, and they are all conspicuous constituents of living reefs. The list will probably be extended to include most, if not all, of the Rendezvous Cay fauna, when the atoll reefs are better known. These thirteen common species are:

Acropora cervicornis
Acropora palmata
Agaricia agaricites
Porites astreoides
Porites porites
Diploria strigosa
Montastrea annularis
Montastrea cavernosa
Meandrina meandrites *(dead only)*
Dendrogyra cylindrus
Isophyllastrea rigida
Mycetophyllia lamarckana
Millepora alcicornis

Zonation of the reefs

Much attention has been devoted in recent years to studies on the zonation of corals on reefs, both of atolls (on Bikini, Tracey, Ladd and Hoffmeister 1948, and Ladd, Tracey, Wells and Emery 1950; and on Arno, Wells 1951 and Hiatt 1957) and other reef-types (for example, Caribbean fringing reefs in the Barbados, Lewis 1960, and Jamaica, Goreau 1959). During the 1961 Expedition an effort was made to obtain data on reef zonation on the windward and leeward sides of each atoll, and a series of transects (figs. 11, 12) were made by swimming across the reefs accompanied by a boatman in a dorey or dugout canoe. Doubtful specimens were collected for later identification, and full notes were made immediately on leaving the water. In cases of doubt a second traverse was made near the line of the first. Unfortunately time only allowed one traverse on each side (windward and leeward) of each atoll, and there is the possibility that the line of transect chosen is not typical. Aqualungs were not used, and the transects could not therefore be carried into depths greater than c. 30 feet. Finally, on the windward sides of atolls, it generally proved impossible to penetrate seaward of the breaker zone: the transect was continued until turbulence made visibility nil. The transect areas were subsequently flown over at heights of 1-200 feet for observation of the zone beyond the breakers, and photographed. Depths and distances are estimated. The limitations of these transects are therefore clear: nevertheless, since in most cases zonation is clearly apparent, and since there is absolutely no published information on these reefs available, the transects are included here.

I. The windward reefs (fig. 11)

A. East reef, Turneffe Islands

The Turneffe Islands are surrounded by a reef which on the east side is narrow, well-defined, breaks surface, and is lined by surf, and on the west side is wider, more diffuse, and generally submerged. Small boats can cross the west reefs at almost any point, but can only cross the east reefs by a number of narrow reef gaps. The east reef was investigated at Calabash Cays: the weather was calm, and the transect was swum from Little Calabash Cay across the reef crest into deep water beyond. The following zones were recognised:

A 1. Seaward shore of cay.

A 2. Sand and rubble platform adjacent to the cay. This is covered with 6-12 inches of water and is some 200 feet wide. It is carpeted with Thalassia and small green algae, including Halimeda. The sand content of the flat diminished seaward, and near its outer edge the platform consists of brittle Porites rubble.

A 3. Reef flat. A sandy area sloping gradually seaward, under 12-18 inches of water, 20-30 yards wide. Small corals (Favia fragum, Porites divaricata) and sea-urchins (Diadema) are scattered in the turtle grass.

A 4. Inner reef zone. A sandy bottom under two feet of water, with scattered colonies up to a foot in diameter of Montastrea annularis, Porites astreoides and Dendrogyra cylindrus, with small colonies of Siderastrea radians. Sea fans and sea-whips are also found.

A 5. Cervicornis zone. Same as zone 4, but with a ground cover of Acropora cervicornis, much of it dead. The Montastrea and Porites colonies are larger (up to 2 feet diameter), but sea fans and sea-whips are not important.

A 6. Annularis zone. This is located immediately to landward of the breaker zone; the dominant colonies are large massive blocks of Montastrea annularis, Porites astreoides, Dendrogyra cylindrus and Siderastrea siderea. Minor constituents include both encrusting and foliaceous Agaricia, scattered Acropora cervicornis, and massively-built but scattered Acropora palmata with branches current-swept lagoonward. The larger colonies are intersected by deep winding channels 6-8 feet deep, floored with coarse, often rippled sand. The zone is 10-15 yards wide.

A 7. Reef-crest (Agaricia) zone. This consists of massive blocks of largely dead coral, covered on the upper surface almost exclusively with Agaricia agaricites. Channels between the blocks are up to 10 feet deep. The zone has a width of only a few yards.

A 8. Outer slope. A platform 10-15 feet deep, and deepening seaward. Colonies are rather small, perhaps averaging 2 feet in diameter, and very varied (Montastrea, Porites, Siderastrea). Between the boulder-like forms are scattered low colonies of Acropora palmata and Acropora cervicornis.

B. East reef, Lighthouse Reef

Lighthouse Reef is surrounded on all sides by a well-defined reef flat edged with living coral, rising on the one side from the lagoon floor and on the other plunging steeply down into great depths. The reefs are thus more clearly defined than those of Turneffe. Several transects were swum in the Half Moon Cay area: immediately southeast of the cay, half a mile to the north, and two miles to the north. That southeast of the cay was in deep water beyond the reef crest, and follows on naturally from that half a mile to the north, which ends at the breaker zone. The two traverses may be combined as follows; Zones B1-5 are from the transect half a mile north of the cay, B6 from that southeast of the cay, while B5 is common to both.

B 1. Reef flat. 3-6 feet deep, and deepening lagoonward; covered with large patches of *Thalassia* over a sandy bottom, with very large specimens of *Manicina areolata* and occasional *Favia fragum* and *Siderastrea radians*.

B 2. *Lithothamnion* pavement: a rocky bottom 2½-3½ feet deep, covered with pink encrusting *Lithothamnion* and numerous unattached nodules 2-4 inches long of *Lithothamnion*. Occasional boulders of *Porites astreoides*, *Diploria strigosa* and *Montastrea annularis*. Width 20-30 yards and over.

B 3. *Palmata* zone. Bottom carrying 2-3 feet of water, with massive colonies of *Acropora palmata* current-swept lagoonward, and smaller colonies of *Porites astreoides*.

B 4. Mixed reef zone: similar in depth to zone 3, but more diverse: in addition to *A. palmata* and *P. astreoides* there are elongate colonies of *Porites porites* and smaller colonies of *Agaricia agaricites*. Nodular *Lithothamnion* is strewn on the floor between the colonies.

B 5. Elevated reef-rock zone: dead, eroded reef-rock, well cemented but highly fretted and bored, rising in small outcrops 12-20 inches above sea level. The sides are fringed with *Millepora* and algae, and are undercut below sea-level. The largest of the emerged patches is only about 4 feet long; and in the intermediate sections there is often a zone of dead reef-rock, similar in appearance but submerged, with clumps of *Millepora*.

B 6. Outer slope. Beyond the elevated reef-rock zone the floor falls steeply from 3-4 feet to over 20 feet, where it levels out to form a deep platform, covered with large and very massively built *Acropora palmata*, which is completely dominant. These are by far the largest specimens seen anywhere on the reefs, forming trees 10-20 feet tall. Between the *A. palmata* there is a carpet of open-branched *Acropora cervicornis*, interrupted here and there by large blocks of dead reef-rock topped with *Agaricia agaricites* and *Millepora complanata*. Between the coral colonies the floor is formed of white rippled sand.

C. East reef, Glover's Reef

Like Lighthouse Reef, Glover's Reef is surrounded on all sides by a sharply defined reef, edging a wide reef-flat, which in the case of Glover's Reef is much more sharply defined lagoonward than on Lighthouse Reef. The reefs are steep-to round the whole atoll perimeter. The windward reef transect was made several hundred yards north of Northeast Cay, about one-third of the distance along the east reef from its southern end. The following zones were recognised:

C 1. Reef flat. A sand flat 3-5 feet deep, covered with a low mat of yellow algae, *Halimeda*, and *Penicillus*, with very scattered colonies of *Porites porites* of brilliant blue colouration.

C 2. *Porites* zone. The floor, which carries 3 feet of water, is covered with broken branches of *Acropora cervicornis*, with scattered live colonies of *Porites divaricata*. Algae are unimportant.

C 3. *Annularis* zone. The reef-flat deepens slightly to 3-4 feet, and the dominant coral is *Montastrea annularis* in large colonies. Also present are boulders of *Porites astreoides*, *Diploria strigosa*, *Diploria clivosa* and *Siderastrea siderea*.

C 4. *Porites-Lithothamnion* zone. Seaward of zone 3, the *Montastrea annularis* ceases abruptly, the sea floor shoals slightly, and is covered with *Acropora cervicornis* rubble and very abundant nodules of pink *Lithothamnion*. The only living coral present is *Porites astreoides*, in small colonies spaced approximately six feet apart (cf. B2, B4).

C 5. Reef crest. Beyond the *Porites-Lithothamnion* zone the floor begins to fall away seaward, as seen in the narrow and intricate passages between the great blocks of dead reef-rock forming the reef-crest. These blocks appear to be formed mainly of *Acropora palmata*, and rise to within a few inches of the surface. They are encrusted with *Lithothamnion*, and near their upper surface with *Agaricia agaricites* (cf. A7). *Porites porites* and *Millepora* are present in small amounts. No living *Acropora palmata* was seen, and only very occasional *A. cervicornis*. There is a fairly dense growth of *Halimeda* on the walls of the reef-rock masses, and a considerable population of zoanthids. The bottoms of the channels consist of coarse *Lithothamnion* rubble.

(C 6. From air reconnaissance it seems that seaward of the breakers there is a well-developed groove-and-buttress zone, consisting mainly of *Acropora palmata*, and probably closely comparable with zone B6 at Lighthouse Reef. Unfortunately it could not be directly observed here.)

II. The Leeward reefs (fig. 12)

D. West reef, Turneffe Islands

By contrast to the east reef (transect A), the west reef of Turneffe does not break surface or rise to a well-marked crest. Reef growth rather begins a considerable distance from the mangrove fringe, from which it is separated by a 'lagoon' $1\frac{1}{2}$-2 fathoms deep, several hundred yards wide, and floored with *Thalassia*. The bottom of this lagoon slopes

gradually from the mangrove fringe to deeper water, and coral colonies are simply distributed on this slope, beginning $\frac{1}{4}$-$\frac{1}{2}$ mile from the mangrove, and continuing seaward for 3-400 yards and more. The transect is taken in the latitude of English Cay, that is about half way along the length of the eastern reef. The following zones are recognised:

D 1. Lagoon, 9-12 feet deep, with a sandy floor thickly covered with Thalassia and gorgonians.

D 2. Thalassia-Gorgonian zone, 5-10 feet deep, similar to zone D1 but shallower, with scattered, mainly small colonies of Montastrea annularis and Porites. The most conspicuous element is the population of large and varied gorgonians. No large algae were seen.

D 3. Gorgonian zone. This is in all respects similar to zone D2, except that the Thalassia carpet is absent, and the bottom is formed of white sand.

D 4. Main reef zone. This has depths of 10-15 feet and a fairly flat bottom. The dominant corals are Montastrea annularis, Diploria labyrinthiformis and Diploria strigosa, with Porites porites and Agaricia agaricites, and small colonies of Dendrogyra cylindrus, Montastrea cavernosa, and occasionally Mycetophyllia lamarckana and Isophyllastrea rigida. Three subzones, from lagoon to sea, may be recognised:

a) the coral colonies are large and scattered, and interspersed with gorgonians and some sponges from zones D2 and D3.

b) the coral colonies are large and closely spaced, with a continuous undercarpet, not more than 2 feet high, of open-branched Acropora cervicornis. Gorgonians and sponges are of small importance.

c) coral colonies are sparser, and the cervicornis carpet gives way to a sandy bottom, populated with very large gorgonians, 4-5 feet high, and sponges.

Subzone (b) is clearly the main reef zone. Only a single small colony of Acropora palmata was seen in this transect.

D 5. Here the bottom slopes steeply into the blue, and is covered with much rubble. It is scattered with various small coral colonies not identified.

E. West reef, Lighthouse Reef

The leeward reef of Lighthouse Reef differs greatly from that of Turneffe. Along the greater part of the west side of the atoll there is a continuous rim of living reef at the surface, edging a wide sandy reef-flat, and falling fairly rapidly from the reef-crest into deep water on the outer side. Because of its leeward location the reef is rarely lined by breakers or surf, except during winter "northers", and then never to the same extent as the eastern reefs. The reef rim is so continuous that small fishing boats can only cross at one or two points: the most important of these gaps lies on the west side of Long Cay and continues northwards almost to the latitude of Saddle Cay. It is clearly shown on air photographs and carries 1-2 fathoms water. At occasional points on the rest of the reef it is possible for fishing boats to find a passage between the coral heads in 4-5 feet of water; one such point lies almost half way along the reef between the main gap and Northern Cay. These points are known to local fishermen.

The transect was made half way along the east reef, near the passage referred to. The following zones are clearly recognised at this point:

E.1. Reef flat. A wide expanse of barren white sand, 4-5 feet deep and more than 200 yards wide, lacking corals, gorgonians, sponges and algae. The sand is fairly coarse, and dead Halimeda is important.

E 2. Gorgonian zone. This is a narrow zone, about 10 yards wide, where the reef-flat is covered with sea fans and sea whips, and sparsely scattered with small colonies of Montastrea annularis. Algae are not of conspicuous importance.

E 3. Cervicornis zone. Seaward of the gorgonian zone, the reef-flat is covered exclusively with a carpet of living loose-branched Acropora cervicornis, in which no other colonial organisms are of importance. The zone is fairly continuously developed laterally, though only a few yards wide, and differs markedly from the zones on either side.

E 4. Reef-crest. At the outer edge of zone E3, the sea floor begins to fall from 4-5 feet in depth to 8-10 feet over a distance of 20-40 yards. The dominant coral is Montastrea annularis in large compound colonies many feet in diameter. Towards the outer edge are large wave-swept colonies of Acropora palmata; in and around them there are abundant encrusting and upright colonies of Millepora complanata and M. alcicornis. Between the Montastrea are globular clumps of Porites porites, and on the sides of the larger Montastrea blocks small subsidiary colonies of Mycetophyllia lamarckana and Isophyllastrea rigida. Encrusting Agaricia agaricites is abundant, but no foliaceous Agaricia was seen. Small boulders of Montastrea cavernosa and Dendrogyra cylindrus were also noted, but no Diploria or Siderastrea. There are numerous sea fans and sea whips in this zone, but quite subsidiary in number to the stony corals.

E 5. Zone E4 ends quite abruptly on the seaward side, commonly as an interrupted vertical wall of Montastrea, with its base at about 10 feet depth. From this point the bottom falls fairly uniformly to depths of 40-50 feet in 100 yards, and is lost in the blue. The bottom is composed of loose white sand with much Halimeda, and occasional small colonies of Montastrea annularis, M. cavernosa, Siderastrea siderea, and Dichocoenia stokesii. There are no gorgonians. Air reconnaissance shows the absence along the leeward reefs of any groove-and-buttress system.

F. West reef, Glover's Reef

The general form of the leeward reefs of Glover's Reef resembles that of Lighthouse west reef; it is continuous, with very few openings, none of them suitable for sailing vessels drawing more than 5 feet. It is steep-to on the seaward side, and edges a wide shallow reef-flat, which falls away steeply lagoonward to a deep lagoon floor. The only important gap is near the old site of Bushy Cay, bearing Northeast Cay 130°, Southwest Cay II 180° (uncorrected compass bearing): it is not a gap in the usual sense, but simply a narrow zone of reef-flat where the edging corals grow less profusely, and cannot be found without local knowledge. The transect is made immediately north of this point:

F 1. Reef flat, at least 100 yards wide, coarse white sand, with much dead Halimeda and Foraminifera, but devoid of larger organisms. It is 4-5 feet deep, and closely comparable to zone E1 at Lighthouse Reef.

F 2. Mixed cervicornis zone. A slightly shallower floor supporting a carpet of Acropora cervicornis, liberally interspersed with small boulders of Porites astreoides and Montastrea annularis, with much upstanding Millepora alcicornis. The zone is some 10 yards wide, and grades seawards into

F 3. Mixed palmata zone. This is much the same as zone F2, but deepens seaward from 5 to 8 feet. Large but scattered Acropora palmata colonies rise from a carpet of A. cervicornis, Millepora, Agaricia agaricites, and many sea whips. This zone forms the reef crest.

F 4. Annularis zone. A zone 30-40 yards wide, falling seawards to 15-16 feet, with a fairly continuous cover of low, small boulder-like colonies, mainly Montastrea annularis, but also M. cavernosa, Porites porites, Diploria clivosa, Isophyllia, Millepora, and Siderastrea siderea.

F 5. This is a continuation downslope of zone F4 into depths of over 30 feet. The limit of the zone was not seen but it is at least 30-40 yards wide. As the water deepens the colonies become more massive and taller. Long buttresses of Montastrea annularis are aligned downslope, and pillars of Dendrogyra cylindrus rise conspicuously between them. Diploria strigosa, Mycetophyllia lamarckana, Isophyllastrea rigida, and conspicuous clumps of Eusmilia fastigiata are also to be seen.

General features of the reef transects

These transects reveal a considerable variety in the atoll reefs --if, indeed, they are representative of more than local conditions-- though a number of common characteristics may be seen. The windward reefs of Lighthouse and Glover's Reefs both show extensive pavements of nodular and encrusting Lithothamnion, which are conspicuously lacking on the windward reefs of Turneffe, the leeward reefs of all three atolls, and over much of the barrier reef. The presence of massive Acropora palmata on the outer slopes beyond the breakers is common on the windward reefs. Montastrea annularis, with Porites and Agaricia, are the chief colonisers of the windward reef flats on Lighthouse and Glover's Reefs. The windward reef of Turneffe, protected from the easterlies by Lighthouse Reef, is quite different: M. annularis is again important, but A. palmata much less so, and the reef-crest consists only of Agaricia agaricites. This is strongly reminiscent of the reef-crest on the barrier reef north of Gladden Spit, where a subsequent transect showed a crest again composed of Agaricia agaricites over dead coral.

The leeward reefs also show important differences and similarities. Turneffe is unique in having no well-defined reef-crest or even a true reef-flat, which may be explained by its doubly-protected location--within a few miles of the barrier reef to leeward, and protected by long man-

grove banks to windward. Lighthouse and Glover's leeward reefs are more closely comparable. In both cases there is a wide, shallow barren reef flat, fringed with a reef complex consisting mainly of Montastrea annularis, Acropora cervicornis, other boulder-like corals, and a little A. palmata in the wave zone. The main apparent difference is in the deep extension seaward of Montastrea and Dendrogyra on Glover's Reef, compared with the dwindling seawards of reef corals from the reef crest on Lighthouse Reef.

The reef complexes illustrated in these six traverses can be interpreted largely as responses to differing degrees of exposure to waves, winds, and wave- and wind-generated currents, affecting both the physiography of the reef and its composition. This latter can best be illustrated by the distribution of certain indicator organisms, such as Acropora palmata, Lithothamnion, and gorgonians. The windward reefs of Lighthouse and Glover's Reefs are most exposed; the leeward reefs and the windward reefs of Turneffe next so; while the most protected of all the atoll reefs is the leeward reef of Turneffe. Sections of the leeward reef of Turneffe in fact bear a striking resemblance to the northern reef-complex of the Rendezvous Cay patch-reef, described by Thorpe and Bregazzi (1960). Taken as a whole, the reefs of Lighthouse Reef and Glover's Reef are closely comparable in their form; while the reefs of Turneffe show sufficient differences from these to stand in a class by themselves.

Lagoon Reefs

Remarks have so far been confined to the peripheral reefs of the atolls, and nothing has been said of reefs situated within the lagoons. In the case of Turneffe no growing coral was seen at any point within the interior lagoons, though it is at least possible that the Thalassia beds of the lagoon floors include unattached colonies of Manicina areolata and Cladocora arbuscula. The shallow lagoon of Lighthouse Reef includes a number of patch-reefs reaching surface, of small area and without pronounced zonation; the dominant coral is Acropora palmata on the upper parts of the patch. In the Glover's Reef lagoon, however, the patches are larger in area, rise from much deeper water, and are very numerous. Many were seen at close quarters from the air, and one was investigated in detail under water.

The patch is located bearing Long Cay 70°, Middle Cay 135°, and Southwest Cays 215° (uncorrected compass bearings); it rises steeply from the lagoon floor, here lying at a depth of 48 feet (8 fathoms). It is roughly circular in shape, with a maximum diameter of about 100 yards, and the mean depth over the greater part of the top of the patch of 4-5 feet. There is a very pronounced zonation of corals on this patch, repeated (as seen from the air) on many others of the Glover's lagoon patch-reefs. Approximately half the rim of the patch on the east and northeast sides consists of a zone of dominantly compact, close-branched Acropora cervicornis, 2-3 feet in thickness and 5-10 yards wide. Scattered colonies of massive A. palmata rise from the cervicornis at intervals, especially near the wave-break zone. Towards the lateral extremities of the cervicornis zone, cervicornis becomes less dominant, and there are large patches of Porites porites and Montastrea annularis. On the

upper surface of the patch, sheltered by the cervicornis zone and close to it, and extending in diffuse lobes round the patch margins, are large boulder-corals, mainly Montastrea annularis, with also Siderastrea siderea, Colpophyllia natans, Isophyllastrea rigida, Porites astreoides, Diploria strigosa, and encrusting Agaricia. Mussa angulosa is present in small but conspicuous clumps, nestling in hollows of larger colonies. The centre of the patch, 4-5 feet deep and with a sandy bottom, has little coral, apart from some straggling, loose-branched Acropora cervicornis and small colonies of Montastrea annularis and Porites astreoides. No Montastrea cavernosa was seen on the reef, and little Millepora.

This zonation suggests that the reefs within the lagoon on Glover's Reef are still sufficiently exposed to respond to the influence of the easterlies, probably in part because of the depth of the water (10-20 fathoms over much of the bottom); whereas on Lighthouse Reef, the effect of wind and waves is damped down by the shallowness of the lagoon.

Relative importance of species in reef-building

The zonation and relative importance of the corals in building the atoll reefs agrees well with what is known from Rendezvous Cay and other West Indian reefs. Taking the profiles as a whole, the dominant coral on the reef flat, and in less turbulent areas of the seaward slope, is Montastrea annularis, followed by other corals of similar habit of the genera Siderastrea and Diploria. In turbulent water and on the seaward slope of windward reefs Acropora palmata is overwhelmingly dominant. It should be noted that in no case was this outer palmata zone pursued to depths of more than 30 feet, and that Newell, drawing on Bahaman experience, described an even lower zone of Montastrea annularis at depths of 30-60 feet (Newell, 1951, 251). At the same time, though he spoke of "West Indian reefs", he clearly had in mind Bahaman examples where the living reefs are set back from the edge of the seaward slope, a condition which does not occur in British Honduras, to which his generalisations do not necessarily refer (Newell and others, 1951).

The primary importance of M. annularis as a reef-builder in the Caribbean area has been stressed in Jamaica by Goreau (1959, 84-85), in Barbados by Lewis (1960), and in the Bahamas by Newell (Newell and others 1951, 23; Newell and others 1959, 213; Newell and Imbrie 1955; Newell and Rigby 1957). Along the upper seaward slopes of windward reefs, however, the Montastrea dominance is replaced by massive branching colonies of Acropora palmata up to 15 feet high (except on the "protected" windward reef of Turneffe), with some A. cervicornis and scarcely any globular colonies. Newell and co-workers noticed similar conditions at Andros, Bahamas (Newell and others, 1959, 213), and Zans (1959) was inclined to rank A. palmata before Montastrea as the most important reef-building coral of Jamaica. Ginsburg suggested that on the Florida reefs A. palmata is "the primary structural element of the reef mass....(it) provides both a framework, around and on which detrital material can accumulate, as well as considerable cobble- and boulder-like debris" (1956). His description of the Florida reefs accords well with windward

reefs in British Honduras, but taking the reefs as a whole, the palmata community is a restricted one, and the globular corals more important. Goreau suggests that the palmata community "probably indicates a reef community in the later stages of development. To provide the shallow conditions necessary for the growth of this coral however, a suitable platform must first be formed; in many cases this is accomplished by the activities of other coral species....predominantly by Montastrea annularis" (Goreau 1959, 85). This reason, and the ecological restriction of palmata to certain areas, indicate that Montastrea is the generally most important reef-builder in British Honduras.

Role of encrusting algae in reef-building

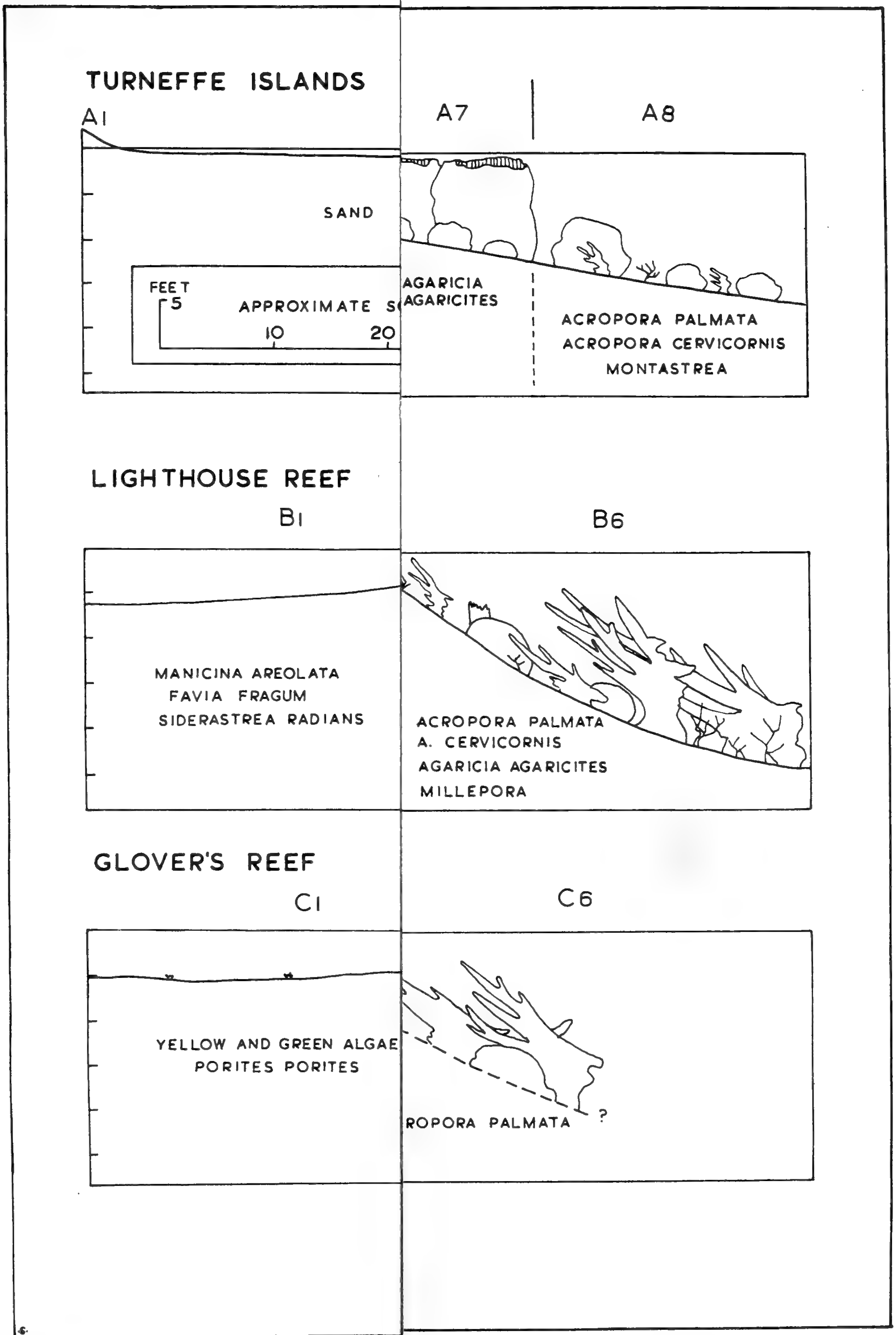
Many recent papers (Ladd, Tracey, Wells and Emery, 1950; Tracey, Cloud and Emery, 1955; Wells, 1957, 614-5) have stressed the importance of encrusting algae in atoll-reef formation, particularly following detailed work in the Marshall Islands. One of the most conspicuous features of reefs in this group is a ridge of pink encrusting algae ("Lithothamnion Ridge" or "Algal Ridge") at the outer edge of the reef flat, exposed at low tide, and best developed on the windward side of atolls (Tracey, Ladd and Hoffmeister, 1948; Emery, Tracey and Ladd, 1954, 25-27). Darwin had long ago recognised this feature, which he termed a "breakwater", at Tahiti and Cocos-Keeling, and it has subsequently been described from Funafuti (Finckh, 1904), Raroia (Newell, 1956, 344-6) (where it is developed on both windward and leeward sides), and elsewhere. Some writers, notably Howe and Setchell, have been so impressed by the importance of encrusting calcareous algae that they consider that modern coral reefs could not exist without them in their present form. Conversely, Gardiner (1903) does not specifically mention an algal ridge in his account of Minikoi, Maldive Islands, and it is known to be absent over much of the East Indies (Kuenen, 1950, 430-433). A similar conclusion has generally been reached in the Caribbean area, though Zaneveld (1958) describes a Lithothamnion reef from the Dutch West Indies. Thus Chapman (Steers and others, 1940, 312-3) found Lithothamnion to be "more or less insignificant" in Jamaican reefs, while Professor Stephenson (1950, 383) found "a very definite dearth of encrusting species between tide marks" in Florida, though he carefully qualified his remarks so as not necessarily to include the whole Florida reef tract.

In British Honduras the transects show that calcareous pink algae form a low pavement on the windward reefs of Glover's and Lighthouse Reefs, which may be a pale, anaemic analogue of the Marshall Island ridges. The pavement is covered with encrusting and nodular forms, with little coral, and is always submerged. The nearest approach in the literature to these pavements is the "Lithothamnion-Millepora ridge" at Andros, Bahamas (Newell and others, 1951, 22), "not exposed at normal low tide, though it may reach within a few inches of the surface." One cannot at this stage assess the significance of the encrusting algae in British Honduras reefs, except to note their dominance over restricted shoal areas of the windward reef. They never seem to occur on leeward reefs, and are probably only poorly developed on protected windward reefs, such as that of Turneffe and much of the barrier reef.

Groove-and-spur systems

Groove-and-spur systems (fig. 13) occur round all three atolls on their windward sides, irrespective of whether land backs the reef edge or not. The only criterion seems to be exposure to wave action. The systems are developed on the upper sections of seaward slopes of reefs on the north- and east-facing sides of atolls. Their distribution is shown in the map, compiled mainly from low altitude oblique photographs taken in 1961, and from the vertical air photo cover. This distribution agrees with data from the Pacific, where groove-spur systems accord well with intensity of wave action (Munk and Sargent, 1948). There is some controversy as to whether they are growth or erosion features. Workers at Bikini (Emery, Tracey and Ladd, 1954, 26-7) believe them to result from slow growth of algae-covered spurs, forming "a most effective baffle that dissipates the destructive energy of the waves and at the same time brings a constant supply of fresh water....to a maximum surface area." On the other hand, similar features have been described where growth of the spurs is not taking place, in basalt or oolite country rock, and here erosion of the grooves must be the chief factor (Newell and others, 1951, 25). Cloud relates them (1954, 201-4) to erosion, following a fall in sea level from a 6 ft. stillstand, itself leading to reef emergence and island formation. "The surf-driven water piles up against the barrier and escapes by flowing seaward beneath the incoming current....Wherever grooves....are well developed without an immediately inboard island the former presence of an island, or other barrier to cross-reef water movement, is suggested, and evidence of the missing island is to be looked for" (203-4). It is unlikely that land or elevated reef have ever completely surrounded the British Honduran atolls on their windward sides: if so, no trace remains (see Sections VIII and IX). The correlation with wave-direction is, however, clear, and it is interesting to note that the spurs are not invariably at right-angles to the reef edge, as usually described, but parallel to the wave orthogonals. Hence, at the north end of Turneffe and Lighthouse Reef, spurs trend at an angle of 60° to the reef in places.

The blanketing of the spurs by slow-growing calcareous algae is much emphasised in Pacific studies (Wiens, 1959; Cloud, 1954, 199), sometimes as evidence of the erosional origin of the systems. However, wherever seen from the air at an altitude of 100-200 feet, the spurs seem to consist of vigorous branching corals, chiefly _Acropora palmata_, with no indication of algal blanketing. Thus these arguments will not apply in British Honduras. Goreau has reported very similar spurs ("buttresses and canyons") from the north coast of Jamaica (1958; 1959, 76-79), which seem to be undoubtedly growth features. The upper surface of these Jamaican spurs is covered with _Agaricia agaricites_, _Acropora palmata_ and _Montastrea annularis_, while the sides consist of gigantic colonies of _Montastrea annularis_ and _Porites astreoides_.


TURNEFFE ISLANDS
A1
A7
A8
SAND
FEET
5
APPROXIMATE S
10
20
AGARICIA
AGARICITES
ACROPORA PALMATA
ACROPORA CERVICORNIS
MONTASTREA
LIGHTHOUSE REEF
B1
B6
MANICINA AREOLATA
FAVIA FRAGUM
SIDERASTREA RADIANS
ACROPORA PALMATA
A. CERVICORNIS
AGARICIA AGARICITES
MILLEPORA
GLOVER'S REEF
C1
C6
YELLOW AND GREEN ALGAE
PORITES PORITES
ROPORA PALMATA
?

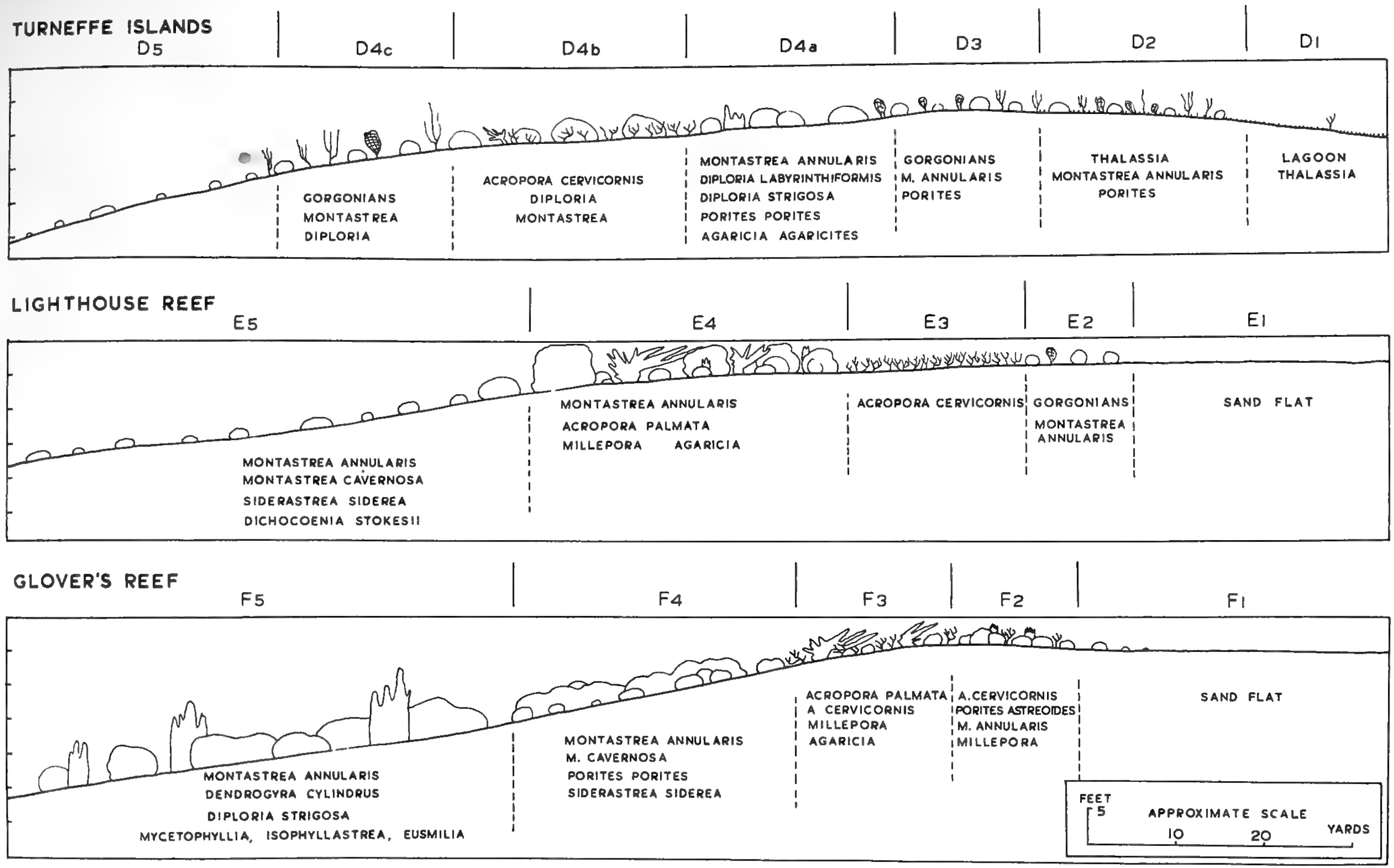
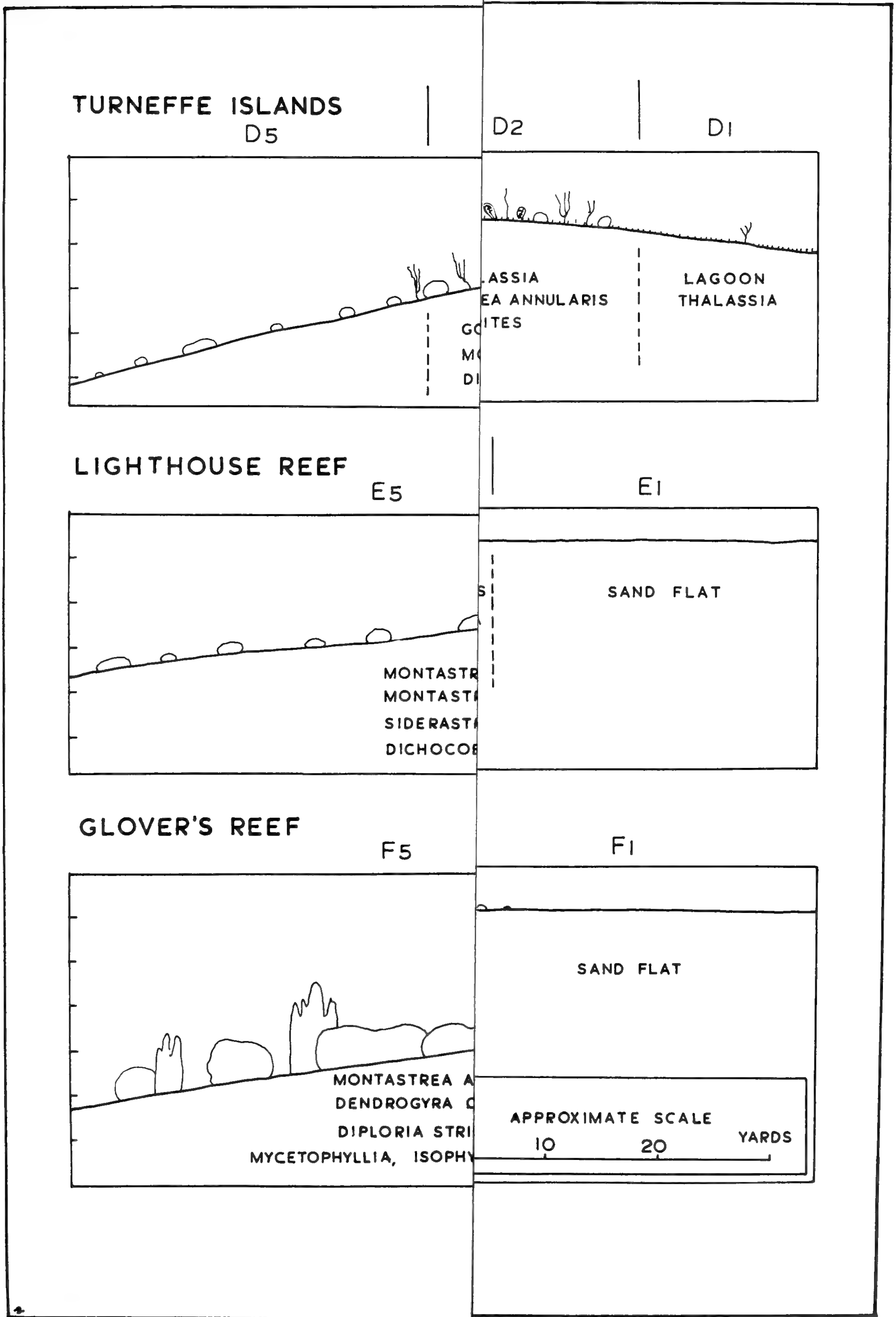


FIGURE 12
LEEWARD REEF TRANSECTS


TURNEFFE ISLANDS
D5
D2
D1
.ASSIA
EA ANNULARIS
ITES
LAGOON
THALASSIA
LIGHTHOUSE REEF
E5
E1
SAND FLAT
MONTASTR
MONTAST
SIDERAST
DICHOCO
GLOVER'S REEF
F5
F1
SAND FLAT
MONTASTREA A
DENDROGYRA C
DIPLORIA STRI
MYCETOPHYLLIA, ISOPHY
APPROXIMATE SCALE
10
20
YARDS

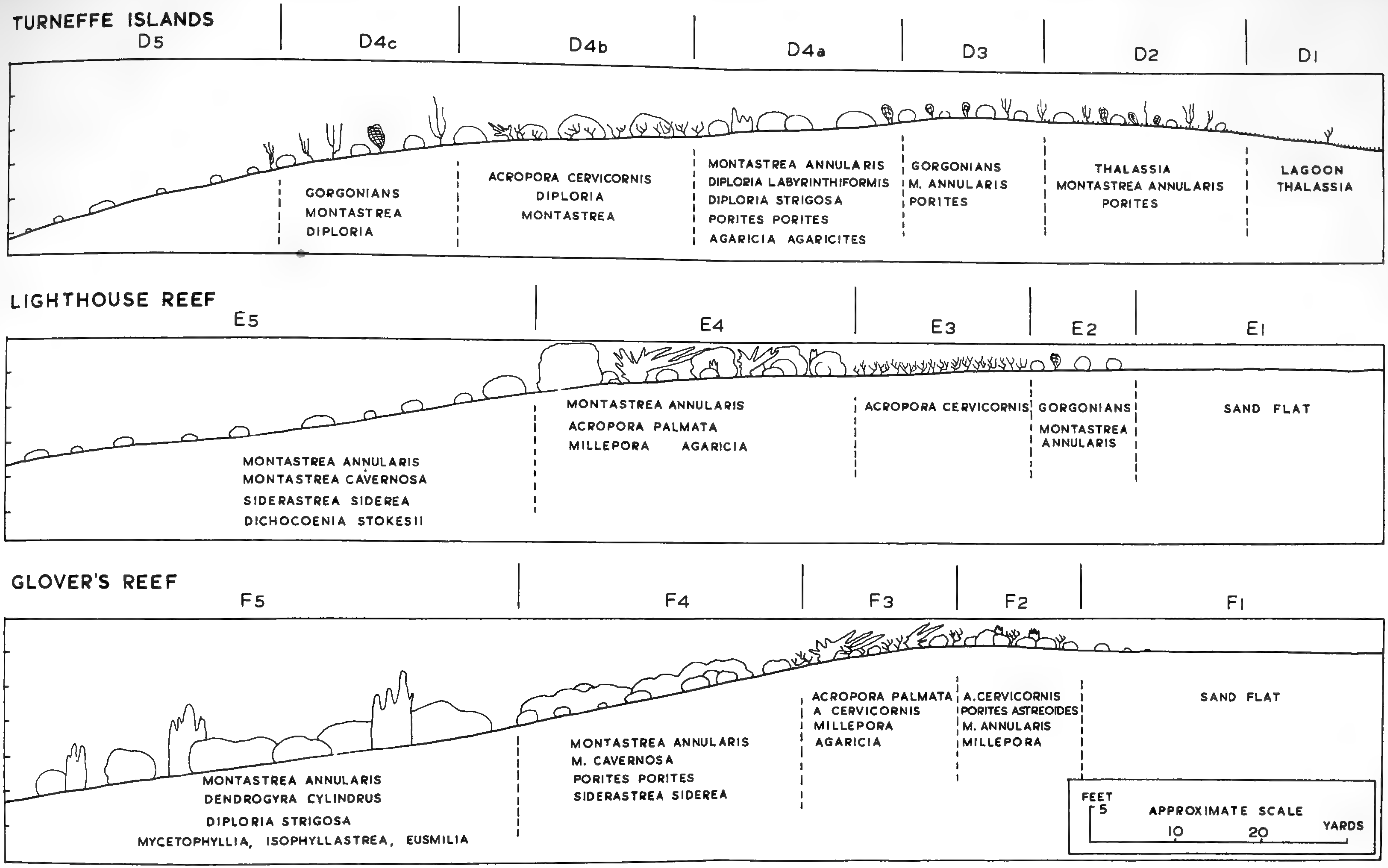
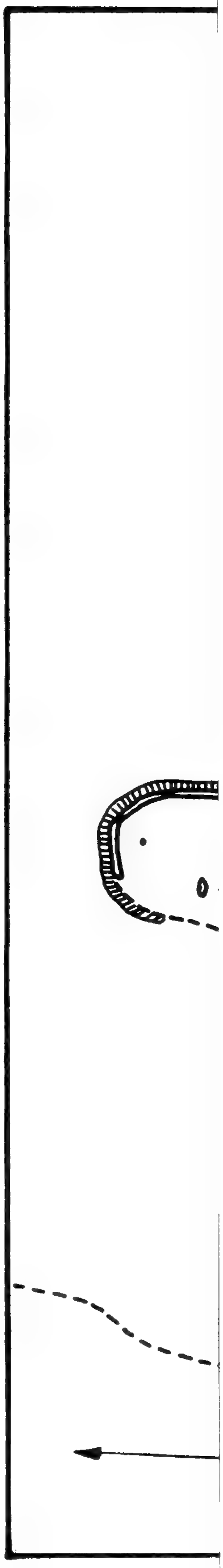
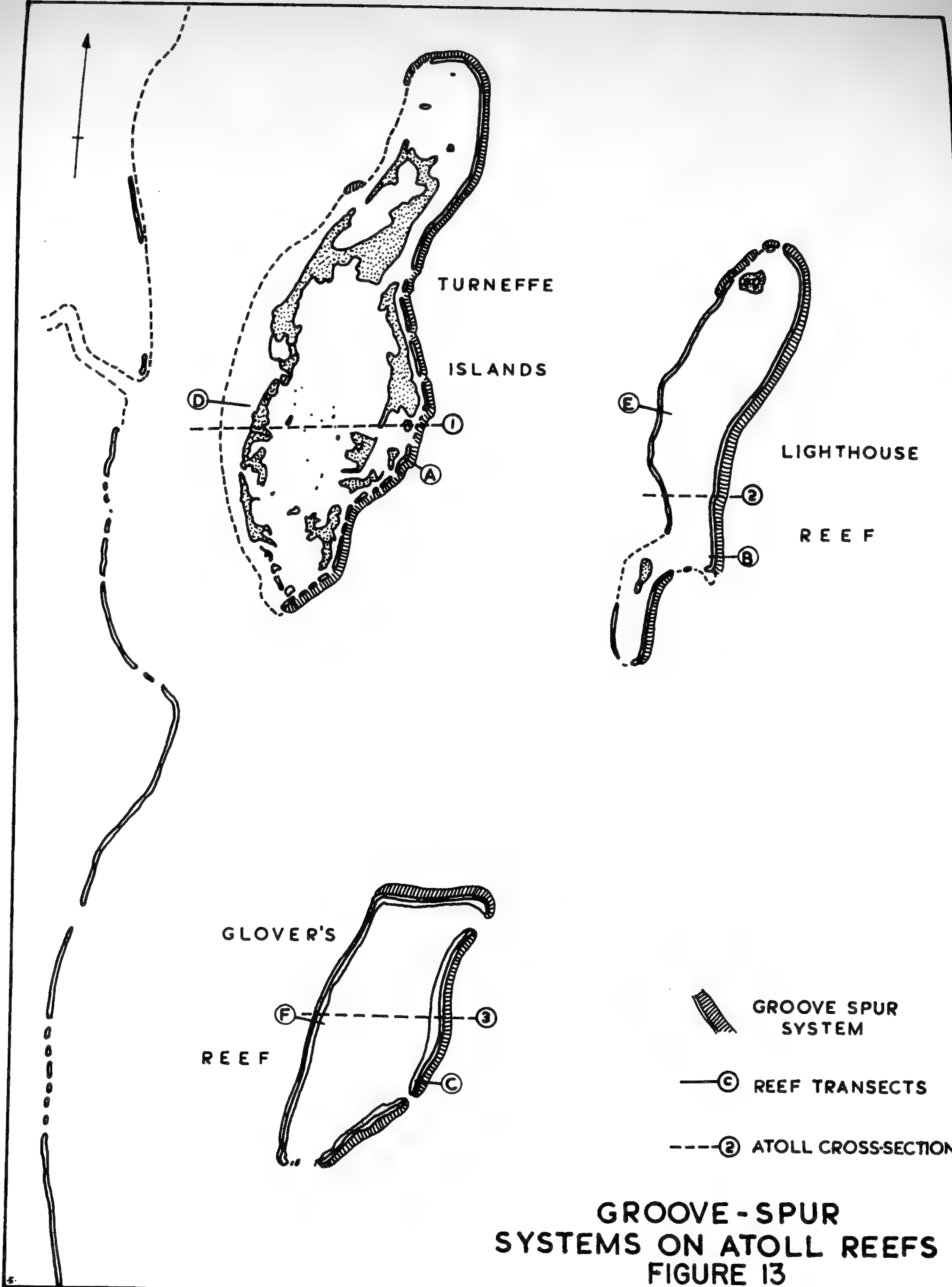


FIGURE 12
LEEWARD REEF TRANSECTS





GROOVE - SPUR
SYSTEMS ON ATOLL REEFS
FIGURE 13

V. TURNEFFE ISLANDS

The dimensions of the Turneffe block (fig. 14) have already been given; it has a maximum length of 30 miles, and varies in width up to a maximum of 10 miles. It is roughly lens-shaped, with its maximum width situated some two-thirds of the distance along the bank from the northeast end. Seen from the sea or barrier reef on the west side, and from the sea on the east side, Turneffe appears as a long, low continuous line of mangroves extending from its southern extremity north of Cay Bokel for all but 5-6 miles of its total length. The sketch-section (fig. 49) shows the main features of the physiography of Turneffe.

On the east, windward side, there is a well-defined narrow reef, described in transect A. The reef-crest zone is narrow, and fringes the outer edge of a reef-flat generally less than $\frac{1}{4}$ mile in width. The reef itself is highly segmented, and has some 23 reef-gaps, mostly less than 50 yards wide, carrying 1-2 fathoms water. On the inner edge of the reef-flat, which is usually submerged by 1-2 feet of water, and intermittently covered with _Thalassia_, algae and small corals, there are small sand cays, some with shingle ridges, located particularly but not invariably at the reef-gaps. From south to north, these sand cays include Cay Bokel, Deadman's Cays (I-V), Little and Big Calabash Cays, with two small cays east of Big Calabash, Soldier Cay and Blackbird Cay, and a large number of small cays near the northeast corner, which have not been visited. They include Dog-flea Cay and Cockroach Cay, but only the latter has been mapped. Aerial oblique photographs of all these cays were taken in 1961, but unfortunately the USAF vertical airphoto cover of Turneffe does not extend to this segment of the reef. Each of the cays visited will be described in detail below.

In places the reef-flat gives way to a deeper moat between the flat and the mangrove, with depths of 4-6 feet, which may in part be current-eroded. The floor of the moat is sandy and rippled. The greater part of the eastern side of Turneffe is fringed not directly with mangrove, but rather with a dry sand ridge, rising up to 5 feet above sea-level, and with a maximum width of some 200 yards. The ridge has a steep sandy shore, colonised by _Ipomoea_ and _Sesuvium_, and its flat crest, decreasing in height away from the sea, is normally covered with coconut plantations (_cocals_) and an undercarpet of the lily, _Hymenocallis littoralis_. The thin line of coconuts is clearly visible on air photographs. As the ridge sinks westwards the coconuts give way to very tall, old, stilt-rooted _Rhizophora_ and some _Avicennia_, now standing on dry land. The mangrove growth is very dense and impenetrable; at some small but unknown distance the dry _Rhizophora-Avicennia_ assemblage is replaced by a broad belt of _Rhizophora mangle_ standing in water. This zone of "wet" red mangrove, often hollow and containing areas of unvegetated mud, forms the eastern margin of the interior lagoons, and divides them from the eastern reef-flat. It reaches its maximum width near Soldier Cay (2 miles) and north of Northern Bogue ($2\frac{1}{2}$ miles). The gaps in the eastern mangrove wall are few but wide: they are, (from south to north) Southeast Entrance (nearly 3,000 yards wide), Grand Bogue (1100 yards), Calabash Entrance (1700 yards) and Northern Bogue (1100 yards, narrowing to 400 yards). Northern Bogue and Grand Bogue are free of living reef at their entrances, and are much used by fishermen; Calabash Entrance

has more reef, but is also used. In places Rhizophora has extended eastwards of the eastern sand ridge (showing that it is, at least in part, a fossil feature), and is beginning to encroach on the reef-flat, as in the long section between Northern Bogue and Soldier Cay. Pelican Cay, detached from the main body of mangrove southeast of Northern Bogue, is in fact a mangrove, not a sand cay, with a dry cleared interior.

The mangrove rim described bounds the interior lagoons of Turneffe on their east side; a second rim bounds them on their west side, but of rather different nature. Generally speaking the western mangrove fringe is narrower and more interrupted than the eastern, and is generally only 500-700 yards wide, and often much less. It is widest at the northwest part of Southern Lagoon, reaching a width of over 2,000 yards. The gaps, too, are very different in character: whereas the "bogues" (Spanish, boca, a mouth) on the east side are wide, the "creeks" or "rivers" on the west are, as their names imply, narrow, often sinuous, sometimes bifurcating channels generally less than 50 yards wide, and varying in depth up to 10 feet. There are 13 of these creeks entering Southern Lagoon north of Cay Bokel; the most important are Blue Creek, Joe's Hole (according to Winzerling (1945) a corruption of the pirate's name 'Jol'), Little Joe's Hole, Grand Bogue Creek, Crooked Creek, Ambergris Creek, and Crickozeen or Grigyson Creek (spelling uncertain). Grand Bogue Creek is most often used: it gives ready access to Grand Bogue, and also to Calabash Cays by way of Northern Bogue. It is very noticeable that each of these creeks is prolonged both seaward and lagoonward by narrow strips of mangrove, so that in the case of Grand Bogue Creek, for example, the channel is approximately twice as long as the intervening mangrove is wide. The creeks are probably kept open by the strong tidal currents which set through them, which are so strong that fishermen often beat around Cay Bokel rather than attempt them. They are in fact drainage channels for Southern Lagoon, to dispose of the great quantities of water poured into it through the eastern bogues. The west rim of Northern Lagoon is much narrower (1-300 yards), than that of Southern Lagoon, and has three small gaps.

The eastern mangrove fringe consists entirely of the red mangrove, Rhizophora mangle. From the sea this presents a seemingly unbroken low wall of vegetation, and requires a practised eye to pick out the promontories which mark the creeks from distances of more than a mile. The eastern fringe is, however, hollow, for air reconnaissance shows that within a peripheral zone of mangrove there are often areas of unvegetated red mud and stagnant pools, with dead mangroves littered on the surface: a desolate landscape. The sand ridge prominent on the east side of Turneffe is here absent, except for a small segment in the extreme northwest, with coconuts. There are no beaches on the east side, except at the foot of this ridge, and one or two minute sandy areas in the south between Blue Creek and Cay Bokel. This is fully in accordance with the sheltered position of the west side.

North of the main mass of mangroves in Turneffe, which encloses the interior lagoons, there are one or two detached mangrove islands, notably Three Corner Cay, Crawl Cay and Mauger Cay. With the exception of Mauger Cay, none have any dry land,they consist of Rhizophora standing in water.

Interior lagoons

The mangrove rims, which seem so continuous from the sea, and which are shown on many maps as rimming a solid land area extending across the whole bank, enclose two lagoons: Southern Lagoon, some 17 miles long, and Northern or Vincent's Lagoon, one-sixth the area of Southern Lagoon, and separated from it by a "hollow" mangrove wall, 1-2,000 yards and more in width. Northern Lagoon was not visited, and was seen only from the air. It has but one small entrance on the windward side, which must greatly restrict the circulation of water and have considerable effects on plant and animal life therein. The depth of Northern Lagoon is not known, but is probably 1-2 fathoms at most.

Southern Lagoon was crossed in many directions in 1960 and 1961. Vermeer found that the depth ranged from 4-8 feet, but elsewhere he says that it is "never more than one fathom deep" (Vermeer, 1959, 18, 93). Soundings in 1961 in the southern part averaged from 1-2½ fathoms, averaging just over 2 fathoms. The greatest sounded depth was in the channel between Pelican Cay and Southeast Bight, carrying 3 fathoms: this is probably a scour channel draining the main body of Southern Lagoon southwards. It seems likely, from observations in 1960, that over most of the northern part of Southern Lagoon, the bottom lies at 2-2½ fathoms depth, and that it is shoaler on the west side than the east. Smith (1941) quotes depths of 1-3 fathoms. According to local informants the maximum depth in the whole lagoon is 21 feet (3½ fathoms) in the northern part.

Wherever seen the bottom is composed of calcareous sand and silt, covered over huge areas with <u>Thalassia</u>. No stony corals were seen, but gorgonians and sponges are found in great numbers. Green algae, chiefly <u>Halimeda</u>, are scattered through the turtle grass, and the most conspicuous animals on the floor are the large star-fish <u>Oreaster</u>, and holothurians. "The floor of the lagoon consists of calcareous mud with admixed shell and coral sand predominant near the eastern entrances, and with organic matter formed from the detritus of eel-grass and mangrove roots present in varying degree throughout the lagoon" (Smith, 1941, 415). It is almost impossible to collect good sediment samples from the lagoon floor, since clouds of fine detritus rise and obscure visibility as soon as the bottom is disturbed, while the subsurface layers are tightly bound together by the roots of grasses and algae. Some of the <u>Thalassia</u> leaves are a foot long.

The lagoon contains a number of islands, all of red mangrove, with no dry land seen. They are strikingly concentrated in north-south lines in the centre and southern parts of the lagoon, where they form "ranges" or groups of cays, such as Crayfish Range. Cross Cay and Pelican Cay (not to be confused with the Pelican Cay on the east reef of Turneffe) are larger individual cays in the south. The cause of this lineation is not known. Most of the lagoon islands, as Vermeer noted (1959, 95), rise fairly abruptly from the lagoon floor, and do not seem to be spreading laterally by colonisation of shoal areas with seedlings; though there are exceptions to this general rule. The origin of the atolls is briefly discussed in section VIII, but it may be suggested here that the islands stand on solid-rock eminences, on the crests of karst ridges developed on an emergent bank during glacially low sea-levels; that, in fact, they

have a solid-rock core, much as envisaged by Agassiz (1894) for some of the cays and reefs of the barrier reef lagoon. Some such basement is required to explain mangrove islands rising from a floor too deep for mangrove colonisation. An alternative suggestion is that they are based on old patch-reefs developed before the growth of the eastern mangrove rim, when seawater had unrestricted access to the centre of the bank, the reefs being asphyxiated as the mangrove rim developed. However the size of some of the islands compared with existing patch-reefs in other atoll lagoons argues against this. On the other hand, comparable lineations, of patch-reefs rather than of islands, will be noted in the accounts of Lighthouse and Glover's Reefs.

The Southern Lagoon sponge beds formerly supported a thriving industry, already well-developed in 1896. "These were fished intermittently and in 1919 were almost completely wiped out by a disease. An attempt to restock a part of the Turneffe lagoon in 1926 failed completely" (Romney and others, 1959, 256). No reports on this mortality seem to have been published, but the beds were again flourishing when badly damaged in 1936. Dr. C.L. Smith visited Turneffe at that time, and concluded that mortality was caused by very high rainfall leading to lowered salinity in the semi-enclosed lagoon basins. No report was published. The beds recovered, but were again decimated in 1939 by some kind of fungus infection, investigated by Dr. Walton Smith of the Marine Laboratory (now Institute of Marine Science), Miami (Smith 1941). According to Smith, there were in 1939 700,000 cuttings planted out in the Turneffe lagoon, including 225,000 sheepswool sponges (*Hippiospongia lachne*), 475,000 velvet sponges (*H. gossypina*), and smaller quantities of other commercial sponges, such as *Spongia barbara*, *S. dura* and *S. graminea*. The disease first appeared in the Bahamas in 1938 (Galtsoff, Brown, Smith and Smith, 1939), and then spread to Cuba and the Florida Keys, appearing in Soldier Bight (Calabash Entrance), Turneffe, in June 1939, killing *H. lachne*. Within seven weeks it had spread to the whole Southern Lagoon, and at the end of July *H. lachne* was everywhere dead and *H. gossypina* dying. In August came a second attack, in the southern part of Southern Lagoon, killing only *H. gossypina*, and in September a third outbreak, killing all the sponges at Long Ridge (between Joe's Hole and Grand Bogue Creek). Noncommercial sponges were not affected, but 95% of the commercial ones were killed. Smith concluded that the mortality was caused by a water-born fungus, carried by currents through the Calabash entrance and then distributed throughout the Southern Lagoon, being most virulent in more stagnant areas. He also noted that the outbreak occurred after a period of no rainfall and high temperatures, leading to high salinity in the lagoon (Smith, 1939, 1941).

The industry never recovered from this disaster, partly because of the war, partly because of competition from the synthetic sponge industry. Piles of the small concrete plates used to plant out the sponges are still found at Calabash Cays, where one of the residents was in 1960 still cultivating a few sponges. There is some talk of reviving the industry, but interest is slight.

Land fauna of Turneffe

The land fauna of the atoll, with the possible exception of the avifauna, is very imperfectly known. A few lizards and snakes have been recorded: Schmidt (1941, 492-7) lists only Anolis sagrei Dumeril and Bibron (found also on the other two atolls), and the common boa, Constrictor constrictor imperator Daudin, but gives no localities. A single specimen of C. c. imperator was taken on Cockroach Cay on the east side of the atoll in 1960 (Thorpe and Bregazzi, 1961, 29), and is thought to be very common throughout the mangrove cays. According to Bond (1954, 2) "An iguana-like lizard (probably Ctenosaura), drab in colour with black bars across the back was noted on several occasions near Rendezvous Point at the northern end of the atoll."

The birds are better known. Devas (1953) has prepared a brief handbook of British Honduras birds, but the well-known text by Bond (1960) is the best field guide. On the birds of the Gulf of Honduras generally, see Salvin (1888, 1889, 1890), Chapman (1896), Griscom (1926). These remarks apply to the sections on avifauna of Lighthouse and Glover's Reef also . Osbert Salvin visited Turneffe, Lighthouse Reef and Glover's Reef in April and May 1862 (Salvin, 1864); and James Bond spent two days at the north end of Turneffe and Cockroach Cay in January 1954 (Bond, 1954). Salvin recorded 15 species and Bond a further 23 species from Turneffe, of which many are undoubtedly passing migrants. Among the common birds are the brown pelican, Pelicanus occidentalis; the man-of-war bird, Fregata magnificens Mathews; and the osprey, Pandion haliaetus ridgwayi Maynard (nests seen by Bond). Other nesting species are Sula leucogaster leucogaster (the brown booby, said to breed on Mauger Cay by Salvin; not seen by Bond; not seen on Mauger Cay in early 1960); Egretta thula thula Molina (Man-of-War Cay, Salvin; not seen by Bond); Sterna albifrons antillarum Lesson (Grassy Cay, Salvin; not seen by Bond); and Chaledrius wilsonia wilsonia Ord (Grassy Cay, Salvin). The most abundant species seen by Bond were Dendroica patechia bryanti Ridgway, Seiurus noveboracensis subsp., Quiscalus mexicanus mexicanus Gmelin, and Icterus oryzivorus L.

Many of the eastern cays are inhabited and have domesticated animals, mainly chickens, dogs and pigs. The largest piggery is at Calabash Cays, where the animals have the engaging habit of wandering between the Big and Little Cays across the reef-flat, up to their bellies in water, grubbing for food on the submerged sandy floor. It is not known whether this is usual behaviour for pigs on reef islands. There are some pigs at Soldier Cay, Cockroach Cay and Cay Bokel, but not at Deadman's Cays, Pelican Cay or Mauger Cay, though obviously the location of the pigs changes with their owners. Rats (Rattus rattus?) are a major pest in the cocals, both on the eastern cays and along the eastern sand ridge, from Rope Walk to Northern Bogue.

Cay Bokel

Cay Bokel (fig. 15) is the southernmost sand cay on the Turneffe bank. Speer described it as a "small short Key....very near joined by a Reef to Turnueff" (1771, 19), and it has probably remained fairly constant

in size, though shifting in position, for several centuries. It is located at the extreme southern end of the eastern surface reef of Turneffe, which here edges a shallow reef-flat 500 yards wide. The cay stands at the inner edge of the flat, near its narrowest point, about 150 yards from the reef itself. Westwards, the water deepens and the reefless bottom lies at depths of $1\frac{1}{2}$-3 fathoms, forming a broad sheltered bay giving good anchorage for ships. This shelf or bay is 500 yards wide, and the floor falls rapidly from its western edge to depths of up to 197 fathoms within 900 yards. It was first sounded by Owen in 1830, and subsequently surveyed in detail by Captain R.W. Glennie, HMS _Mutine_, in 1921 (cf. _West Indies Pilot_, I, 1956, 461, and charts). The cay itself has not been previously described in detail.

The island is roughly triangular in shape, with sides about 35 yards in length, and has a total area of only 1,000 square yards. Its surface is low and sandy--a coarse sand, with much _Halimeda_, shell fragments, and brittle pieces of coral, mostly of small size. Along the eastern side, a little small shingle, mainly _Acropora cervicornis_, has been thrown up on the shore, but has not formed a ridge. No part of the cay rises more than 2 feet above the sea: it is highest on its south and east sides, and slopes westwards. The leeward shores are flat and sandy, the windward shores rather steeper. The wave refraction patterns affecting the cay are clearly seen from the lighthouse: the main east reef is lined by breakers, and water flows transversely across the reef-flat to the eastern shores, while a much less powerful but well-marked set of waves refracts round the south end of the reef and approaches the cay from the south and southwest.

In recent years the cay has been retreating northwards and probably westwards away from the reef. This is shown by the steep seaward shores and the lower prograding lagoon shores (note the spit at the north point), and also by beachrock. No beachrock is seen on the cay itself, but there is a single line 55 yards southwest of the cay, extending for about 10 yards. The rock dips seawards and must mark a former shoreline. Between it and the cay the bottom is shallow, with small corals in thick _Thalassia_, and ranges in depth from 1 foot near shore to 18 inches near the beachrock. In order to control this retreat, residents have attempted to protect the seaward shores with conch-shell ramparts, but to little effect. Conchs are taken from Turneffe to Belize, and piles of their shells also lie near the pier on the north side of the island. How far this retreat is due to long-term changes and how much to catastrophic hurricane damage is not clear; but Cay Bokel bears the marks of the spectacular and intense power of hurricanes. The present lighthouse--a steel-frame tower--stands near the south shore of the cay: it immediately overlooks the foundations of a second lighthouse, now 7-12 yards from the shore, washed by waves and standing in water 1-2 feet deep. Fifteen yards to the north, on the cay itself, are the remains of a third lighthouse foundation, partly obscured by sand. The lighthouse base now awash is a substantial concrete structure; and between it and the cay are the remains of a concrete-block seawall, presumably built since the base, and now much broken and itself awash. This light was destroyed by the 1931 hurricane. The other base, also of concrete, has been strongly tilted, and is now only partly exposed; this was destroyed in the hurri-

cane of 1945 (information from the lighthouse keepers). Whether the beachrock dates from the period when the first of these lighthouses was built on dry land is unknown; if it does, then the cay was formerly larger than now. All the evidence, however, indicates continuing retreat in the same general direction.

Of vegetation, little remains. Jefferys noted "Low Bushes" in 1775, and Glennie "bushes and coconut palms, about 50 feet high" in 1921, but the bushes have now disappeared. Coconuts are the only larger plants on the cay, and there are some two dozen of them. The ground surface is bare, save for a patchy cover of Ambrosia hispida toward the leeward side, and a few lilies, Hymenocallis littoralis, to seaward. There are a few small Rhizophora seedlings on the southeast shore, beneath the conch rampart, but no mature mangroves; they are probably short-lived strays from the main Turneffe mangrove areas to the north.

The 36 foot high lighthouse tower is tended by a keeper with a substantial hurricane-proof house; he keeps some pigs. Apart from this there are no permanent inhabitants. The cay is so small that its continued existence if struck by a major hurricane is not without question. It is said to have been named by the Dutch buccaneer Cornelis Jol in the seventeenth century (hence also the bogue known corruptly as "Joe's Hole"), from the Dutch word for elbow or corner, i.e. the cay at the southern elbow of the Turneffe bank (Winzerling, 1946, 29).

The Deadman Group

This is a group of five small cays standing on the eastern reef-flat, between the reef-edge and the eastern mangrove rim, some four miles from the southern end of Turneffe. They are located toward the southern end of a reef segment, bounded by gaps giving access at northern and southern ends to Rope Walk and to the cays. The eastern mangrove rim behind this section of the eastern reef lacks the sand ridge so well developed farther north, and consists of pure Rhizophora with little or no dry land. The reef-flat along this reef-segment varies in depth, but generally carries less than 2 feet of water, and between some of the cays (such as II and IV) much less than a foot. The reef itself is steep-to; the main water currents are transverse to the reef with little refraction, and are deflected north and south by the mangrove wall. The pouch-shaped depressions back of the reef-gaps are scour-channels associated with the outflow of water draining laterally along the reef-flat and through the gaps. Because of the steepness of the reef-front, waves break heavily on the reef, and a heavy swell comes through the gaps, making them dangerous for small boats without local knowledge. The cays were visited in May 1960, and are here described from south to north, numbered for convenience I to V.

Deadman I (fig. 16)

Measured along its main axis, Deadman I is 110 yards long, and varies in width from 20 to 32 yards. It is aligned transverse to the main reefs. Its physiography is relatively simple: the cay is everywhere low, but rises at its eastern end to not more than 3 feet above sea-level, where

it is composed of small blackened shingle. In the middle section of the cay the shingle is less widespread and intermixed with coarse dark sand, while at the western end, the shingle disappears and the cay is wholly composed of sand. The western end is little more than a foot above the sea. Westward of the cay a submarine spit extends for 10-20 yards, composed of fresh white sand, parts of it drying at low tide, and colonised by several Rhizophora seedlings. The cay is clearly extending lagoonward at its western end, though there is no corresponding evidence of retreat at the seaward end. Along the south shore, beachrock is exposed for nearly 20 yards: it is a soft, poorly indurated rock, passing inland under the cay sands. It is 12-18 inches wide, shows no marked dip, and its surface is covered with a spongy mat of blackish algae. The water immediately offshore is sheltered and subject to considerable overheating; numerous Rhizophora seedlings grow here.

Most of the cay has been cleared for cocal, and apart from an intermittent ground-cover of Sesuvium, Euphorbia and grasses, vegetation is very sparse. At the low western end the new sand has been colonised by Sesuvium and a couple of Tournefortia bushes. Rhizophora seedlings are found round the whole cay margin in shallow water, but the only mature mangrove is a gnarled Avicennia on the seaward shore. The coconuts which cover the island rise to a height of about 30 feet.

The island is not inhabited, though at the time of our visit in early 1960 there was a palm-leaf shelter at the west end of the cay.

Deadman II (fig. 16)

Deadman II is located 150 yards north of Deadman I, and rather more distant from the seaward reef-edge. It approaches a circular shape, with N-S and E-W diameters of 80 yards. It, too, is low: the seaward shore is composed of medium to fine shingle rising to a crest 2-3 feet above the sea. From this maximum height the surface declines eastwards to the leeward shore, which is wide, low and sandy, and faces a broad shallow bay between the cay and the mangrove rim. The bay has depths of only 1-2 feet, and near the cay is much colonised by Rhizophora seedlings. There is no mangrove zone on the cay itself, and only a few tall Avicennia. Laguncularia racemosa (white mangrove) was identified on the leeward shore by its distinctive club-roots.

The cay is planted to coconuts, but unlike Deadman I the undergrowth has not been cleared. Round most of the cay margins the upper beach is covered with Sesuvium and Euphorbia (on the leeward beach by Sporobolus and other grasses), passing inland under a dense zone of Conocarpus and Suriana bushes, from which the coconuts rise. As far as seen, there are no remnants of broadleaf forest on these cays. Tournefortia gnaphalodes was seen at one point on the northwest shore. The cay is uninhabited, and we found the sandflies troublesome.

Deadman III (fig. 18)

This cay lies about 170 yards north of Deadman II, and is the smallest of the group, having maximum dimensions of but 50 yards (E-W) and 35 yards (N-S). Though 100 yards back from the reef-edge, there is still small shingle on the seaward shore, rising about 1½ feet above

the sea. The rest of the island is sandy, and one has the impression that it is growing westwards fairly rapidly. A fresh sand spit at the west end is colonised by small Rhizophora and Avicennia. The vegetation resembles that of Deadman II: the main ground cover is Sesuvium, with some Ipomoea and Sporobolus. Tournefortia is found on the shingle ridge, and Conocarpus forms a dense zone on the leeward side. Between the shingle ridge and the Conocarpus zone are a number of low coconuts. Avicennia is also found at the north point. There is no beachrock or habitation.

Deadman IV (fig. 17)

Deadman IV is the largest of the group, separated from Deadman III by a shallow channel 20-30 yards wide, carrying only a foot of water or less, with a soft sandy floor scattered with worm mounds. The island is oval-shaped with its longest axis aligned north-south; its maximum dimensions are 125 yards (N-S) and 95 yards (E-W), and its total area only two-fifths of an acre. It is located closer to the eastern reef than the other Deadman's Cays, and hence the seaward shore consists of coarser material--less shingle, but more coral rubble, some of it lying in shallow water offshore. Back of the rubble zone the cay surface is sandy, and the north, south and west shores consist of fine sand. There is a little shingle forming lobes to north and south of the main seaward rubble zone. The seaward shore overlooks a rubble-strewn reef-flat with depths of 1-2 feet; the leeward shore faces a very shallow, sheltered sand bay, with restricted circulation, and many young Rhizophora seedlings.

The vegetation cover is dense and not easy to penetrate. Along the southern part of the seaward shore there is a hedge of Tournefortia, and elsewhere on the windward side the upper shore is covered with Sesuvium and Euphorbia. On the leeward shores Sesuvium is again widespread, with a little Euphorbia and much Sporobolus and other grasses. The centre of the cay is covered with a dense thicket of coconuts and bushes, mainly Conocarpus; no tall broadleaf trees were seen. The Rhizophora colonists in the leeward bay have been mentioned, and in addition, the low leeward shore is lined by scattered, more mature Rhizophora, Avicennia and Laguncularia, with many dead trees and branches, particularly of Avicennia. The mangrove does not, however, form a distinct zone separate from the sand cay.

Deadman V (fig. 18)

Deadman V is the most northerly of the group: it stands about 400 yards north of Deadman IV, and like it is close to the reef. In spite of this, however, the island is almost wholly built of sand, with only a very little shingle at the extreme eastern end, and some small pitted coral blocks lying on the reef-flat offshore. No part of the island rises more than 2 feet above the sea.

The cay falls into two sections. The eastern one is low and formed of rather grey humic sand. It is triangular in shape, with the apex facing east: its maximum E-W length is a little more than 50 yards, while the base of the triangle, along the west side, is 70 yards long. The vegetation has been cleared for coconuts, and apart from these and a small area of Sesuvium consists mainly of Sporobolus virginicus and

Cyperus planifolius beneath the palm trees. The second section of the cay lies immediately adjacent to the sand area on its west side; it consists solely of Rhizophora mangle, with little or no dry land. This forms a zone elongated in a north-south direction, with approximate dimensions of 70 x 35 yards. Along the south shore of the sand area there are a number of small Rhizophora seedlings, with a single mature tree at the east point, and the shore itself is lined with the dead roots and branches of a more extensive mangrove zone. Most of this cay probably originated as a mangrove island, and owes its present height above sea-level to more intense sedimentation near the east reefs. The dry areas may have been cleared for cocal in recent times. It is of interest that Owen's 1830 MS chart shows two small cays at this point, suggesting the existence of a narrow channel between the two segments of the cay, which has been filled in by mangrove growth in the last 130 years.

The Deadman's Cays are rather different in aspect and origin from other sand cays on this coast. They do not occur in association with reef gaps and refraction patterns, as is generally the case, and they are located where the eastern mangrove rim approaches closest to the eastern reefs, that is, where the "reef-flat" is narrowest. As noted, the eastern sand ridge of Turneffe does not occur at this point. The east reef here is exposed to considerable wave action, and much debris is washed across it and finds no means of escape. Some is undoubtedly flushed through the gaps--hence the "pouches"--but most must accumulate in front of the mangrove rim. This accounts for the general shallowness of the inter-cay area on the reef-flat, and the cays themselves probably represent only incidental, local, greater accumulations of sediment. The cays near the reef have some shingle, those farther back none (there are exceptions). The purely sandy areas may have originated as mangrove-capped shoals (Cay V), which, producing a further obstruction, would help to trap more sediment on the windward side. This would lead to ecological changes and colonisation by dry-land vegetation. This transition from mangrove has undoubtedly been aided by man's intervention in clearing for coconuts. None of these cays show evidences of erosion so common elsewhere, presumably because of the great supply of debris. The cays are probably growing both toward the mangrove rim, and, more slowly, laterally towards each other. Currents across the reef-flat will probably long keep open the present channels between the cays, but once they coalesce sufficiently to form a continuous line, then the intervening leeward depression between cays and mangrove would soon fill in, and a continuous sand-rimmed mangrove area be formed. This may in part explain the formation of the main eastern sand ridge of Turneffe. Finally, the structure of the cays--their lack of height, abundance of sand, small development of shingle ridges--can only reasonably be ascribed to the protective influence of Lighthouse Reef against the prevailing easterlies. This and other questions concerning the Deadman's Cays are discussed in Section VIII.

Calabash Cays

Northward of the Deadman Group the east reef extends with many interruptions, including the Grand Bogue entrance, to Calabash Cays, a distance of about 7 miles. Calabash Cays are located toward the southern end of an arcuate segment of reef $1\frac{1}{2}$ miles long, which extends across the greater part of the Calabash Entrance (to the interior lagoon). The Entrance itself is a wide gap in the eastern mangrove rim, which is here rimmed by a sand ridge on its windward side. The group includes four cays (Owen charted 3 in 1830), two of which (Big and Little Calabash Cays) are named. The mouth of the Entrance itself carries at least 1 fathom of water, and its floor is sandy, with large north-south orientated ripples. Near the reef, particularly where backed by the mangrove rim, the water is shallower, and though access to the two main cays can be obtained in about a fathom of water, by keeping close to the mangroves, the cays themselves stand on a reef-flat carrying less than a foot of water.

Little Calabash Cay (fig. 19)

Little Calabash is the most southerly of the group, and is located at the southern end of the reef segment (cf. Transect A, Section IV). It has been much altered by man and now has little of interest. The cay is regular in shape, with maximum dimensions of 95 x 60 yards. It is highest on its northeast side, where a sand beach with much *Halimeda* rises to a crest approximately $2\frac{1}{2}$ feet above the sea. The surface slopes gently to the low leeward shore, with no marked irregularity. There is a little evidence of marginal erosion, in the undercutting of coconut trees on the northeast shore, but this is probably much retarded and even outweighed by human agencies. The cay is the centre of the Turneffe coconut export trade, and at the north end there is a marked peninsula, about 15 yards long, consisting of nothing but split coconuts. Conchs are exported, too, and their shells form the shore near the pier and also along the seaward side, where they have probably been dumped to give protection. Erosion along the south and southeast shores (facing the reef gap) has been sufficient in the past to necessitate the building of a pile-wall on this side, backed with conch shells. This appears to have completely halted any natural erosion on this side. No beachrock is exposed near the cay. The seaward shore overlooks a reef-flat, covered with *Thalassia*, and carrying only 6-8 inches of water. The pier on the leeward side gives anchorage in 7-8 feet of water.

The pier itself is 30 yards long, and has at its end a transverse landing stage 40 yards long, with a large warehouse. This can accomodate at least two coconut boats at a time, and these rather ungainly, deep-hulled vessels, including the *Corozal Packet*, make regular runs to Belize. Little Calabash represents a clearing house for the Turneffe coconuts, which are brought here in small boats from as far as Rope Walk for transhipment. There are several small sheds on the island, and one substantial hurricane-proof house. The buildings include a small commissary, where a limited amount of supplies can be obtained on about three days a week. Black pigs are numerous here. The vegetation consists entirely of some $1\frac{1}{2}$ dozen coconut trees, with a scattered ground cover of grasses and a low blue-flowered plant.

Big Calabash Cay (fig. 20)

Big Calabash Cay lies about 300 yards northeast of Little Calabash, with which it is connected by a very shallow sandy reef-flat, partly covered with Thalassia, across which, as noted, the pigs wander freely. The cay is aligned NNE-SSW, parallel to the reef, and is about 170 yards long. Its width varies from 35 to 55 yards, and it is uniformly low and sandy. The maximum height is reached on the east side, and lies between 2 and 3 feet above the sea. There is no shingle on the island, but in several places there are banks of conch-shells, and at one point a considerable accumulation of the small concrete plates formerly used for cultivating commercial sponges. At the south end of the cay there is a spit of fresh sand.

The vegetation has been removed for coconuts, and nothing remains apart from these and a sparse growth of coarse grasses, except for some peripheral mangroves--chiefly Rhizophora seedlings close inshore, and a couple of taller Avicennia trees near the north end. The coconuts form a ragged canopy only 20-30 feet high. This island has been settled for many years, and has several houses, especially one substantial building at the southeast point; rainwater is obtained from vats. The Big Calabash settlement was formerly more important, especially between 1900 and 1939, when it was the centre of the sponge industry, but since then Little Calabash has handled the coconut industry on account of its deeper anchorage. There are several small wooden jetties round the island, and the leeward bay gives anchorage of 4-5 feet.

East Cays One and Two

East and north of Big Calabash are two smaller islands, here named in order of proximity to it, Big Calabash East One and East Two Cays. East One (fig. 20) is separated from the main cay by a shallow channel only 14 yards wide, carrying up to 12 inches of water, with numerous Rhizophora seedlings. The cay itself is small and rounded, with a diameter of 40-50 yards. Its eastern shore lies close to the reef, is straight, and formed of coarse blackened coral rubble; it has little worn shingle and no sand. The rest of the island is sandy with varying amounts of small shingle, and nowhere does it rise more than 3 feet above the sea. It is covered with bushes, mainly Suriana maritima and Conocarpus erectus, with several low Rhizophora and taller Avicennia trees round its margins. Two distinct clumps of coconuts, totalling less than a dozen trees, rise towards the centre of the cay.

Big Calabash East Two (fig. 19) is smaller, and is located about 90 yards north of East One. It consists of a narrow strip of land 50 yards long and generally less than 10 wide, with some shingle at its east end. The greater part is low and sandy, and does not rise more than 18 inches above the sea. It is prolonged westwards by a fresh sand spit. The vegetation is low and windswept, and consists only of peripheral mangroves (Avicennia and Rhizophora, with many shoreline Rhizophora seedlings), a central thicket of Suriana maritima and coarse tall grasses, and two or three low young coconuts.

On none of these cays was any beachrock seen.

Soldier and Blackbird Cays

Rather less than 3 miles north of Calabash Cays, the east reef of Turneffe swings eastwards in a prominent elbow to its most easterly point. North of the elbow the reef is wide and strongly developed, with a wide sandy reef-flat, and well-marked groove-spur system on its seaward slope; south of it, the reef and sandy flat are narrow, but the reef growth is no less vigorous than that to the north. Immediately south of the elbow itself, two cays are located: the southernmost and largest is known as Soldier Cay; the northernmost is unmarked on charts but is known locally (according to fishermen at Calabash Cays) as Blackbird Cay.

Soldier Cay (fig. 21)

Soldier Cay is 145 yards long and has a maximum width of 55 yards. It stands some 50 yards back from the reef-edge, and parallel to it. The cay is fairly regularly shaped, and of simple physiography. The seaward, southeast shore, 110 yards long, is formed by a steep ridge of grey shingle, well interlocked, rising to a fairly constant crestline 5.5 feet above sea-level. In the south and centre of the cay the surface slopes gradually from this ridge crest to the shore on the east side; the interior surface is of fine grey sand with scattered coral fragments, tight-packed, and with the upper layers discoloured with humus. The lee shore itself is formed of fine white sand. At the northeast end of the cay (which faces the sea north of the main reef elbow) the shingle ridge continues round the shore, decreasing in height and in size of constituent material, and appears along the northern part of the lee shore as a distinct ridge rising 3-4 feet above the sea. This leeward beach ridge is broad, with a rounded profile, and contains more sand than medium shingle; the cay surface between it and the seaward shingle ridge consists of grey sand with scattered fine shingle. The two cross-sections (fig. 22) of the cay show these features plainly. There is no evidence of erosion round the cay margins, except at the south end, where the old grey sand area is bounded by a distinct low cliff-line. However, a fresh sand peninsula 20 yards wide projects up to 15 yards in front of the undercut zone, and is now being colonised by vegetation.

The most distinctive feature of the physiography of the cay is the platform on which it stands, for here, uniquely in British Honduras, is a segment of drying reef. This begins near the north end of the cay, borders its seaward side, and extends southwards for over 200 yards. Its average width is about 20 yards. It consists of detached loose boulders, generally less than 2 feet in diameter, much blackened and pitted, piled on a rock pavement which lies slightly above low tide level. The platform itself is thus submerged at high tide but many of the blocks remain exposed--many of them are so weathered as to be no longer identifiable. None are in the position of growth, and all are probably thrown up from the reef-front by wave action in time of storms: the location at the eastern elbow, where refraction would be greatest, may help explain the feature. The surface of the rock platform is irregular (though curiously unlike such possible emerged reef-rock surface as at Half Moon Cay), and at low tide contains isolated pools of water subject to great overheating. Small fish and morays are seen in the deeper pools, mollusca are very abundant, but stony corals are absent. Large algal

growths are not common. The surface seems to slope lagoonward and to be highest near its seaward edge; the number of blocks is also greatest near the wave-break line, and diminishes lagoonwards. Neither north nor south of this small area is any drying reef to be found.

The whole cay is planted thickly with coconuts, and the natural vegetation has been almost entirely removed. The cay is said (Romney and others, 1959, 245) to have been planted at one time with sapodilla (Achras sapota L.) and mahogany (Swietenia macrophylla King), but no trace of these or any other broadleaf trees remains. The steep seaward shingle ridge bears oval-shaped patches of Sesuvium portulacastrum, and low spray-swept bushes of Tournefortia gnaphalodes, with a little scattered Euphorbia. At the north end of the cay are bushes 4-5 feet high of Suriana maritima, and an undercover of Sesuvium and Euphorbia, but apart from this, a patch of Sesuvium on the new southern sand spit, and sparse Sporobolus underneath the coconuts, the cay surface is bare. Most of the coconuts are about 40 feet high; but one at the south end is about 15 feet higher than the rest. There are numerous Rhizophora seedlings in shallow water near the cay, along the west and south shores.

There are several houses and sheds on the island, none substantial, but no-one was living there at the time of our visit in 1960. There is a small wooden jetty at the south end of the cay, and in shallow water to westward two palm-leaf fish-traps.

Blackbird Cay (fig. 23)

Blackbird Cay is situated about 100 yards NNE of Soldier Cay: it is a small, crescent-shaped island, transverse to the reef-flat at this point, some 70 yards long. It is widest at its seaward side, where it fronts a dry zone of coral blocks, mainly massive palmata slabs. The cay is highest on this side, rising from a beach of Halimeda sand to a core of large shingle 3 feet high. This core has a diameter of 25 yards. To leeward the shingle is finer, and the island is prolonged southwestwards by a spit of fresh sand with fine shingle. The north side of the cay, which faces the open sea across the reef north of the main elbow, is also fronted with palmata slabs. The channel between Soldier and Blackbird Cays has a maximum depth of 15 inches.

The southeast seaward shore is fringed by a zone of mangroves, unusual in so exposed a location, including both Avicennia and Rhizophora about 15 feet high. Three solitary young coconuts rise to a height of 20 feet to leeward of the mangroves, from a ground cover of Sesuvium. Between coconuts and mangrove are a number of low but dense Conocarpus bushes. An unidentified black bird was nesting on the cay at the time of our visit.

Pelican Cay

From the Soldier Cay elbow, the eastern reef trends slightly northwestwards for nearly seven miles to Northern Bogue. The eastern mangrove rim lies 600-700 yards back from the reef-edge; and though the eastern sand ridge is here well-developed, it is divided from the reef flat by a

narrow fringe of Rhizophora. Only a single cay is found along the whole of this section of the reef. Owen in 1830 (MS H57) marked two distinct cays, "Pelican Cays", one small island some distance south of a larger one, and the two cays are both marked, and so named, on later charts. The cay was visited in 1960 and photographed from the air in July, 1961, when only a single cay existed. We were unable to ascertain whether the former two cays have grown together, or whether one has been destroyed, perhaps in a hurricane; the latter view seems most likely.

The cay (fig. 23) is rectangular in shape, and aligned with its long axis parallel to the reef, i.e. north-south. The dry land area has maximum dimensions of 100 yards N-S, and varies from 40 to 60 yards in width E-W. When visited in 1960 the whole dry land area was surrounded by a belt of Rhizophora mangle, with a little Avicennia and Conocarpus on its dry-land margin. This mangrove rim was interrupted only in three places, two of them artificial boat harbours rimmed by conch shells. The cay surface probably does not rise more than 18 inches above the sea; it is flat and featureless, composed of grey sand with no shingle. The interior of the cay has been completely cleared and planted to coconuts, and has only a scanty undergrowth, mainly of grasses with a little Sesuvium. When photographed from the air in July, 1961, however, the Rhizophora rim of the northeast side had been completely cleared, revealing a narrow, white-sand shore. Southeast of the dry sand area there projects a rounded mass of tall bushy Rhizophora, forming a peninsula about 35 yards in diameter.

The cay is inhabited and has two huts, one occupied in 1961 by a Carib fisherman. It is quite possible that this island originated as a mangrove cay, and that its present appearance is almost wholly man-made.

The Cockroach Group

Between Northern Bogue and the northern end of the main mass of the Turneffe lagoon mangroves, between the east reef and the eastern mangrove rim, are a number of mangrove-sand cays and sand cays here termed "the Cockroach Group" (fig. 24). Cockroach Cay is one of the larger islands in the group, the only one inhabited, and the only one visited and mapped. The group extends from Dogflea Cay in the north for a distance of 3 miles, ending in the south at a large mangrove cay about 500 yards long, set at an angle to the reef. Cockroach Cay and the cays to the north were visited or seen at a very early stage in this investigation, but the extent of the group to the south of Cockroach Cay was not realised until they were flown over and photographed at the close of the second expedition. Each cay was photographed, looking west, from a height of 200 feet, and the following remarks are based on these photographs. The area has never been mapped in detail or shown on charts, and unfortunately only the southernmost part is included in the air photograph cover. A very general sketch map has been prepared showing these islands; it is hoped that they may soon be fully mapped, and our record of the British Honduras cays so completed.

The group includes 28 cays altogether, of which five are longer than 250 yards, 15 are between 20 and 100 yards long, and the remaining 8 are mere specks of land, mostly mangrove. The smaller cays, especially in the south, are mainly and sometimes entirely mangrove; the larger cays, with the exception of the southernmost, show a distinct zonation into seaward sandy beach, sand area with bushes, and leeward red mangrove zone. Coconuts are not generally found, except on Cockroach Cay, which has been cleared and given over to cocal. Altogether, four cays, including Cockroach and Dogflea, lack mangrove entirely, and of the rest, 8 have large sandy areas covered with bushes, with mangrove restricted to the leeward side, and the remaining 18 are wholly or mainly mangrove, many with only very small areas of dry sand. Perhaps half a dozen of these cays would repay detailed mapping. To some extent they resemble the Deadman's Cays farther south, but otherwise they form a distinctive cay-type on the British Honduras atolls, not being associated with reef-gaps. The chief dry land vegetation seems to consist of bushes such as *Suriana* and *Conocarpus*.

Cockroach Cay (fig. 25)

Cockroach Cay is situated near the northern end of the group, with six cays to the north. It is a long narrow island, aligned parallel to the reef edge, here interrupted by a gap immediately south of the cay. The island has a maximum length of 310 yards, and varies in width from 55-60 yards. Along its seaward shore for a distance of 180 yards the beach is formed by a shingle ridge rising to a crest 3 feet above sea level. Back of the ridge the cay surface declines to the leeward shore and is composed of sand with large amounts of blackened and broken coral, much of it still recognisable. The greater part of the northern section of the cay, however, is sandy; and a fresh sand peninsula is also building southwards from the southern end of the island. The leeward shore is everywhere low and sandy, facing a shallow bay with large numbers of *Rhizophora* seedlings close inshore.

The vegetation has been almost wholly cleared for coconuts, now planted in orderly rows, with little ground vegetation apart from grasses and *Euphorbia*. At the southeast end of the leeward shore, however, there is a thicket of old mangrove and low bushes, from which we obtained a specimen of the common boa, so widespread in the Turneffe mangroves.

Dogflea Cay, the northernmost in the group, is low and sandy, with a narrow sand beach. It is covered with a thicket of *Suriana* bush, from which rise four low coconuts.

The Northern Cays

Three prominent cays stand to the north of the main mass of the Turneffe lagoon mangroves: Three Corner Cay, Crawl Cay and Mauger Cay. The first two were seen from close range, and the last visited. Crawl Cay and Three Corner Cay are almost wholly mangrove, with little dry land. Three Corner Cay is shaped as its name implies; Crawl Cay is elongated east-west and is convex to the north. Mauger Cay is also orientated east-west and is convex northwards, and it is the only one with dry

land. Unfortunately the dry land area is so small, the vegetation so tall and dense, and the deflecting influence of the cast-iron lighthouse so great, that no map could be made, in spite of some effort. The eastern and western lobes of the cay consist of Rhizophora with no dry land. The central part, which has been cleared, is low and sandy, with prominent clumps of Rhizophora along both its north and south shores. The cay has clearly suffered some erosion (though it is located nearly $1\frac{1}{2}$ miles south of the reef-edge and well within the lagoon), since the whole of the north shore of the cleared area is bounded by a thick masonry wall. The cay surface does not rise more than 2 feet above the sea. The cleared area is small and irregularly-shaped; it has less than a dozen coconuts, all less than 15 feet high. The sandy areas are covered with Sesuvium, Ageratum maritimum, and Cyperus planifolius. A very wide-spread shrub, 2-3 feet high, with fleshy leaves, cannot unfortunately be identified. Towards the west end of the cleared area is the 64 foot high open-frame light-tower, with three substantial houses for its keepers. According to Winzerling (1946, 59) the cay received its name from the women prisoners (mugeres) which pirates brought here after the sack of Bacalar in 1648. The West Indies Pilot refers to a prominent "portion of a stranded wreck on the northern edge of the reef, about 1 3/4 miles north-north-eastward of Mauger Cay" (1956, 462), and this was seen again in 1960.

The Eastern Sand Ridge

As already stated, the eastern side of the eastern mangrove rim of Turneffe is fringed for much of its length by a sand ridge. This forms the seaward shore on the south side of Northern Bogue, both sides of the Calabash Entrance, and on both sides of Grand Bogue. It was either visited or seen at close quarters at Northern Bogue, Harry Jones (north side of Calabash Entrance), Calabash Cays, and Rope Walk (its most southerly extent). Between Northern Bogue and Rope Walk it forms a fairly continuous feature, though often hidden from the sea by a narrow belt of mangrove. It generally rises, with some local shore undercutting, to a crest 3-4 feet in height, consists of sand with little coarser material, and declines westward to pass under the inner belt of lagoon-fringing mangroves, Rhizophora and Avicennia. The ridge is almost entirely planted to coconuts, with an intermittent undercover of Hymenocallis and grasses, and along the shore a little Tournefortia, Suriana, Ipomoea, Sesuvium, and in places Coccoloba uvifera. It has clearly been built up along the seaward edge of the mangrove by the great amounts of debris being washed across the eastern reefs, which cannot otherwise be disposed of. It is thus analagous with the formation of such mangrove-sand cays as Cay Caulker and Long Cay on the coastal shelf, though on a much larger scale. Whether it grew at a uniform rate along its whole length, or consists of several distinct patches subsequently united, is not known; and whether it is currently undergoing growth or not is questionable. The widespread growth of mangroves in front of the ridge, and its undercutting elsewhere, suggest that it is in fact a fossil feature.

Dixon (1956) in his memoir on the geology of southern British Honduras figured a section of elevated beachrock from this ridge, which he described as marking a former shoreline 7 feet above the sea. He did

not give its location. Vermeer, however, though he did not find this or any other raised beach on Turneffe, quotes Dixon's brief caption and reproduces his photograph (1959, 87, 95, 96)(in both cases the photograph is reversed left to right). The existence of this beach, together with other "raised beaches" on Ambergris Cay and Long Cay, Lighthouse Reef, which Vermeer described, led him to correlate them all: "Each of these was on separate geomorphological units and each stood at a height of 5 to 7 feet above sea level. ...The uniformly raised beaches clearly point to a negative eustatic change in sea level" (1959, 87). One of the conclusions of the present study is that no such fluctuation can yet be demonstrated, and is in fact on present evidence extremely doubtful; this may be illustrated by reference to the Turneffe example.

Harry Jones Point (fig. 26), northern side of Calabash Entrance, was visited in April 1960, and the existence of the raised beachrock noted. The area was mapped, with special reference to the beachrock outcrop, which was subsequently recognised as that figured by Dr. Dixon. I am grateful to Dr. Dixon for sending me some further photographs and comments on it. Dr. Dixon visited the area with the British Honduras Land Use Survey Team, and Dr. Romney has also given me his comments. In May 1961 the area was again visited, levelled, and augered.

Beachrock outcrops only along the north-south trending shore of Harry Jones, for a total distance of 220 yards. To the north the shore sweeps westward in a broad bay; to the south the shore becomes low, trending westward into Calabash Entrance. The sand ridge is here 30-50 yards wide, and is covered with coconuts, ending abruptly at the margin with tall Rhizophora and Avicennia. The undergrowth beneath the coconuts consists of Sesuvium, Euphorbia, Hymenocallis, grasses, and Iresine celosia. At the easternmost bluff (i.e. the most northerly extent of the beachrock) are a number of Tournefortia and Suriana bushes, and the whole of the east-facing shore, where the beachrock outcrops, is clothed with dense, overhanging Coccoloba uvifera. The crest of the sand ridge varies in height, but is generally 3-4 feet above sea level. It rises highest at the eastern bluff, reaching 5.5 feet above approximate low tide level. The surface of the sand area slopes back towards the mangrove rim, and I doubt whether any part exceeds 6 feet in height in the Harry Jones area.

The beachrock also varies in height. It is highest at the eastern bluff, where the outer edge of its upper surface lies 1' 8" to 2 feet above approximate low water level; it slopes southwards along the shore, and for the greater part of its extent lies only slightly above mean sea level. The southernmost sector lies at about low water level, and is covered with beach sands and banks of dead Thalassia. The outcrop is being eroded, especially at the eastern bluff, and many blocks have been undercut, broken off, and now lie on the shore. It is difficult at the bluff itself to determine original dip: the surface of the beachrock, roughened and pitted by erosion, seems approximately horizontal, though Dr. Dixon thinks it slopes upwards from the sea. Away from this bluff, the beachrock dips seaward like any other beachrock, and indeed looks much the same. At the bluff itself the beachrock is overlain by the ridge sands, here rising to rather more than 5 feet above sea level, and the question arises, how far does the rock extend beneath the sand, and

and how high does it become? In this connection, Dr. Dixon writes (personal communication, 1960):

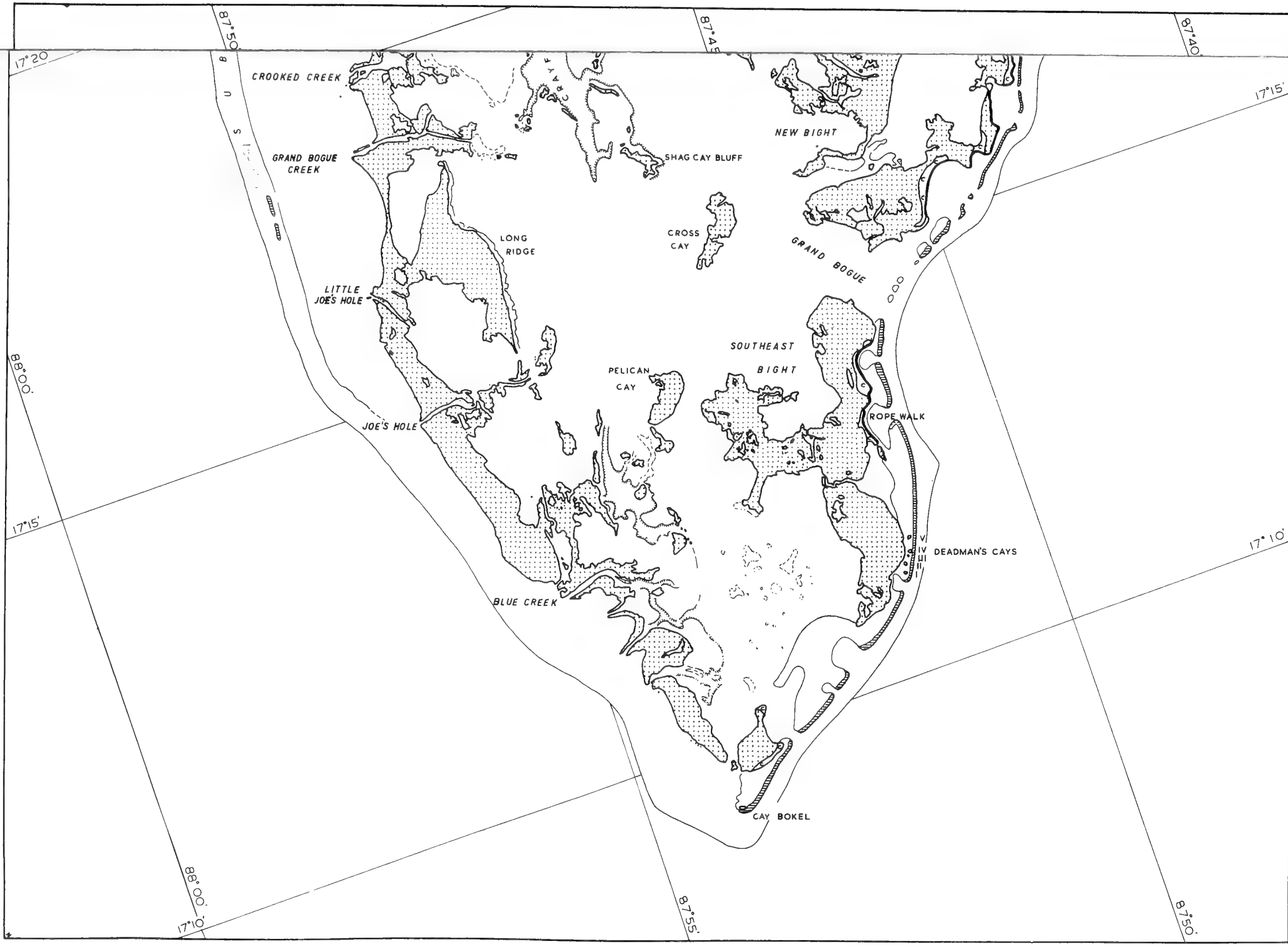
> "....the beachrock slopes upwards away from the sea and disappears under a thin covering of grass and sand. ....Starting about 10 yards or so back from the top of the bank we put down some hand auger holes to examine the soils, and just below the surface there was a layer much more compact than the soft material below it. This compact layer got softer as the water-logged mangrove area at the west side of the cay was approached. We assumed that it was the same beachrock, rotted perhaps by the fresh water in the soil, but the height was only a rough guess."

In 1961 we put down two auger holes, one 5 yards inland from the bluff, striking beachrock at 2 feet depth, one 10 yards inland, not striking beachrock at all. The beachrock thus rises at this point to 2-2½ feet above approximate low tide, and as the sand surface steadily declines westwards, cannot get much higher than this.

The true beachrock at Harry Jones thus has a vertical extent of about 3 feet, does not rise more than 3 feet above the sea, is 5-10 yards wide at most, and extends for over 200 yards. The lateral (as distinct from normal transverse) gradient I believe indicates tilting of the whole exposure, since pronounced lateral dip is not a feature of intertidal beachrocks. Lateral tilting has raised the north end to give abnormally high beachrock at the bluff; in this connection we can refer to the drying reef at Soldier Cay a few hundred yards to the north. This is the only exposed reef in British Honduras, and might reasonably have been involved in--indeed, caused by--the Harry Jones tilting.

The softer rock a few inches below the surface described by Dr. Dixon from augering is not, I believe, rotted beachrock, but "cay sandstone" (Kuenen 1933; see Sections VIII, IX), the induration resulting from fresh water percolation and evaporation. If the true beachrock and this sandstone are continuous, then they must form a plate 200 yards long and up to 50 yards wide: altogether improbable for beachrock formed by intertidal cementation on medium-gradient beaches with small tidal range. Unfortunately time did not allow a full programme of augering in 1961 to trace the extent of this "cay sandstone" induration.

In my view, this beachrock owes its appearance to tectonic, not eustatic causes; but even if it can be shown to be eustatic, then it cannot be referred to a sea-level higher than 3 feet above the present, and certainly not to any 6 foot stillstand.


87°50'
87°45'
87°40'
17°20'
17°15'
CROOKED CREEK
GRAND BOGUE CREEK
NEW BIGHT
SHAG CAY BLUFF
CROSS CAY
LONG RIDGE
GRAND BOGUE
LITTLE JOE'S HOLE
SOUTHEAST BIGHT
PELICAN CAY
ROPE WALK
JOE'S HOLE
88°00'
17°15'
DEADMAN'S CAYS
V
IV
III
II
I
17°10'
BLUE CREEK
CAY BOKEL
88°00'
17°10'
87°55'
87°50'

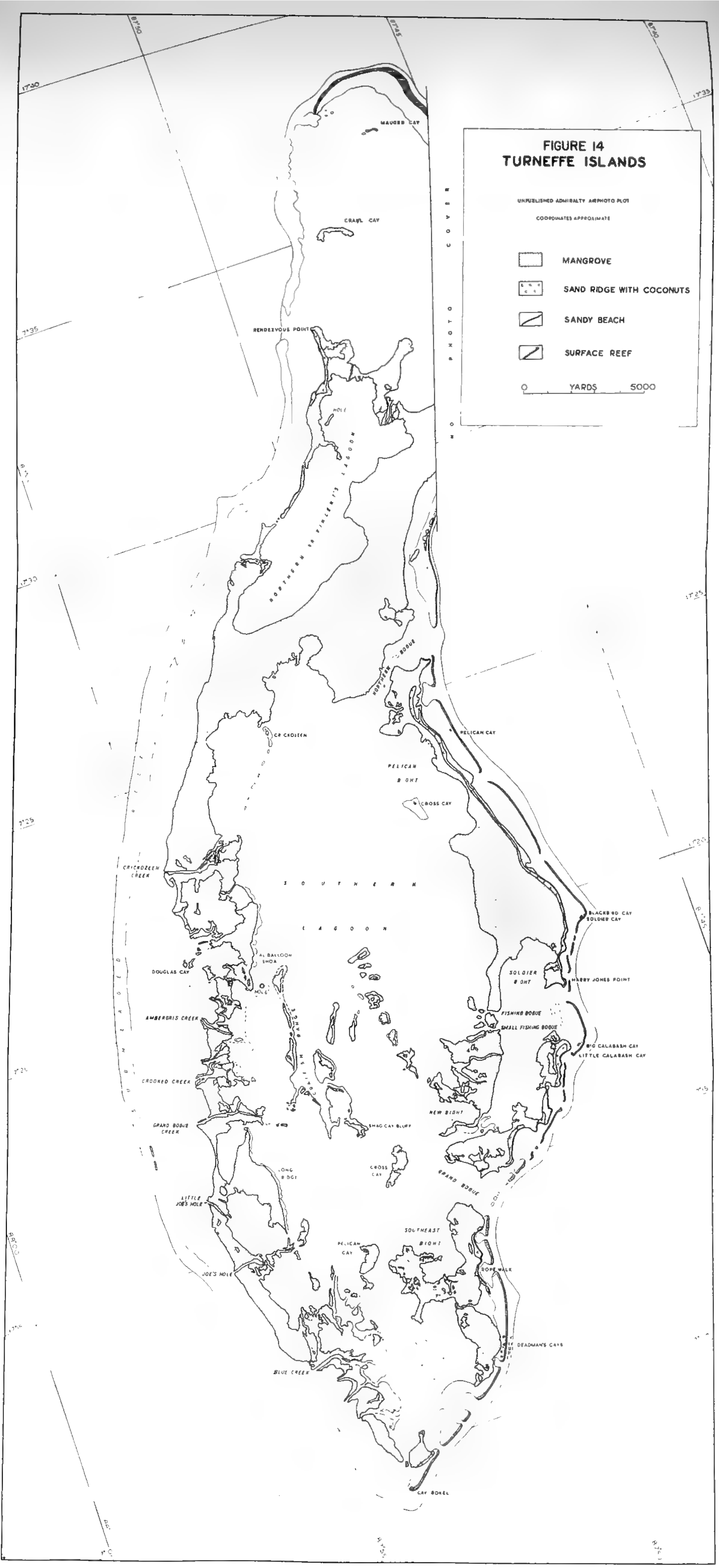
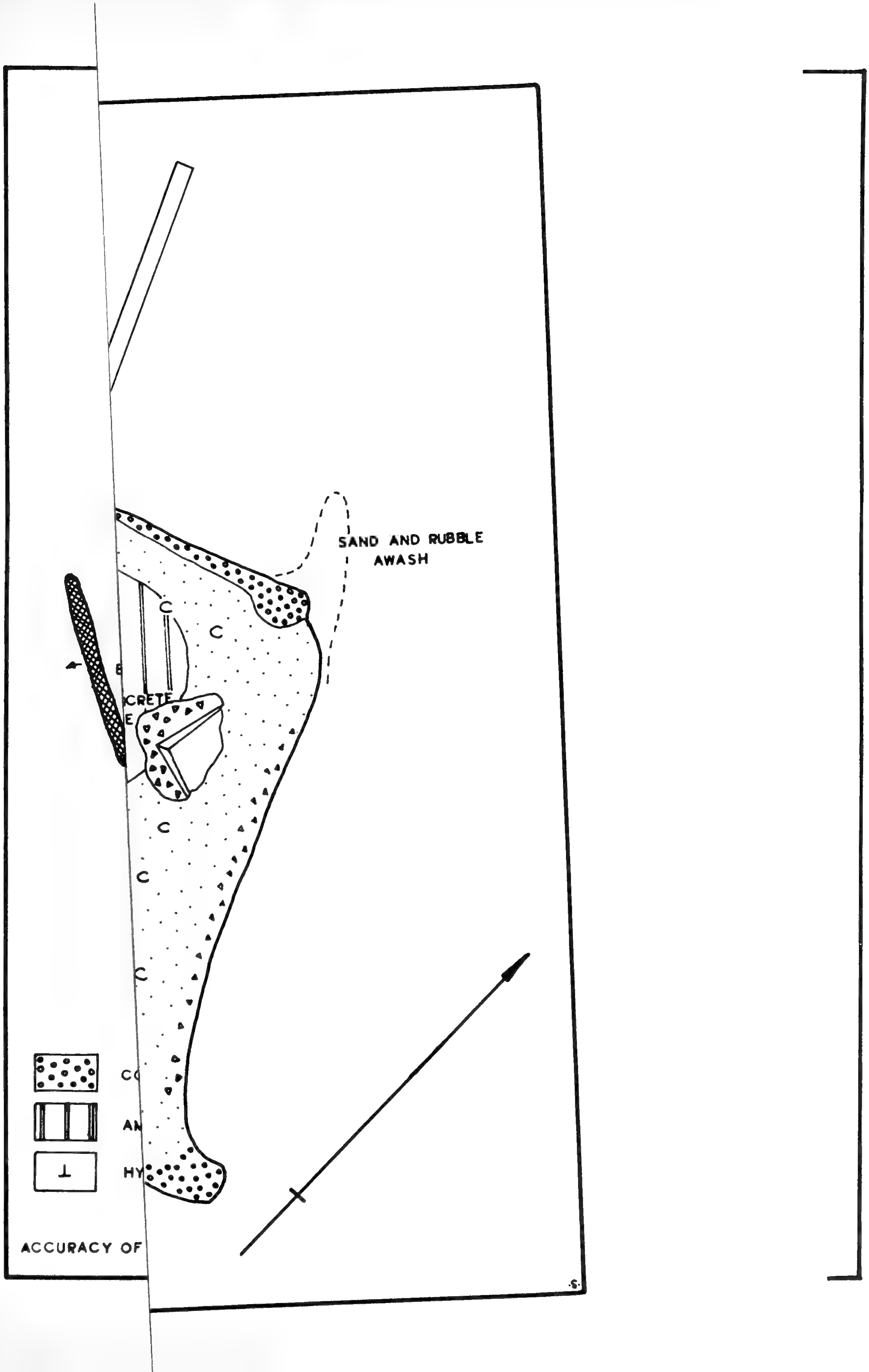


FIGURE 14
TURNEFFE ISLANDS



SAND AND RUBBLE
AWASH
C
C
CRETE
E
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C
C
CO
AM
HY
ACCURACY OF

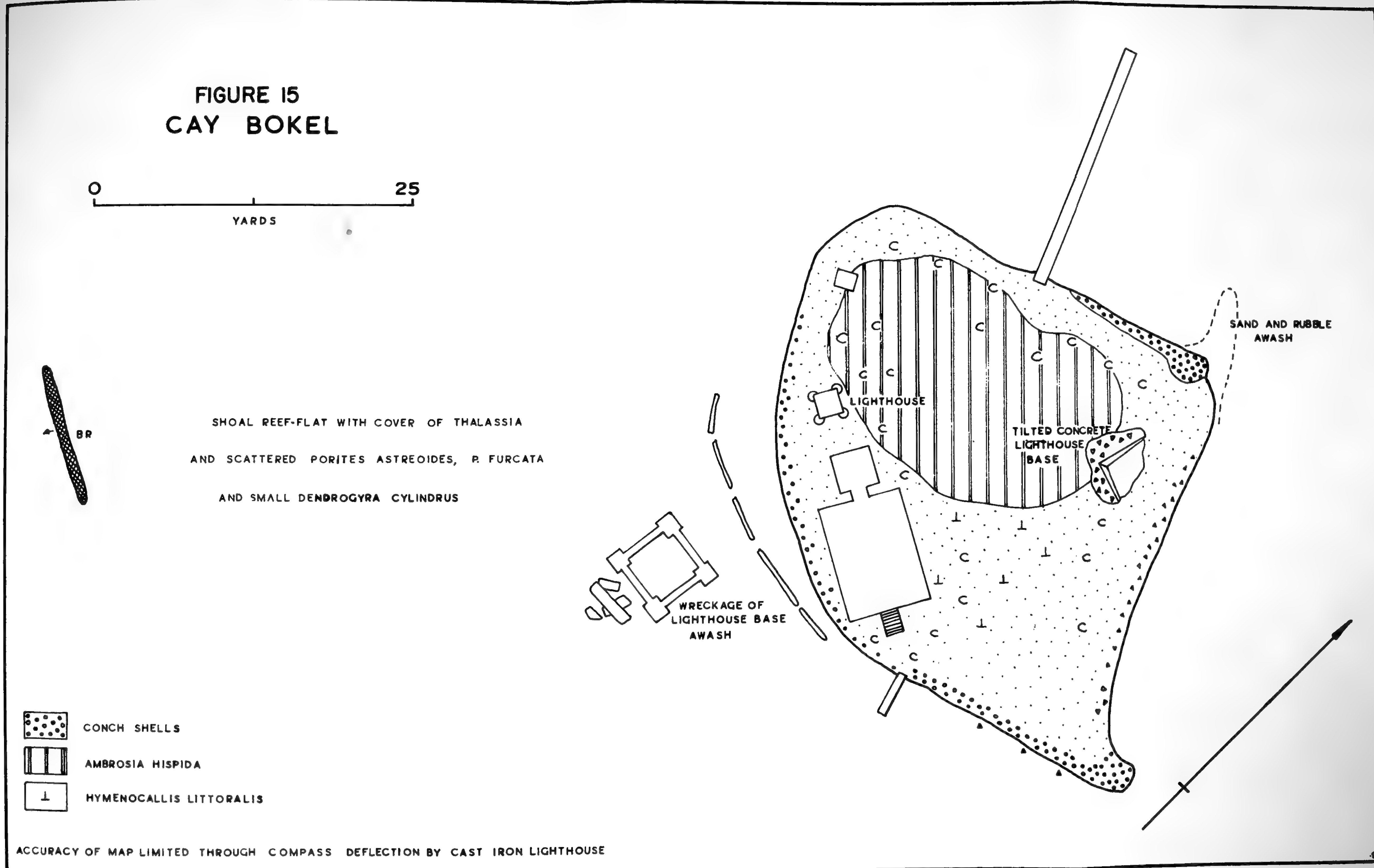


FIGURE 15
CAY BOKEL
0
25
YARDS
BR
SHOAL REEF-FLAT WITH COVER OF THALASSIA
AND SCATTERED PORITES ASTREOIDES, P. FURCATA
AND SMALL DENDROGYRA CYLINDRUS
LIGHTHOUSE
TILTED CONCRETE LIGHTHOUSE BASE
SAND AND RUBBLE AWASH
WRECKAGE OF LIGHTHOUSE BASE AWASH
CONCH SHELLS
AMBROSIA HISPIDA
HYMENOCALLIS LITTORALIS
ACCURACY OF MAP LIMITED THROUGH COMPASS DEFLECTION BY CAST IRON LIGHTHOUSE

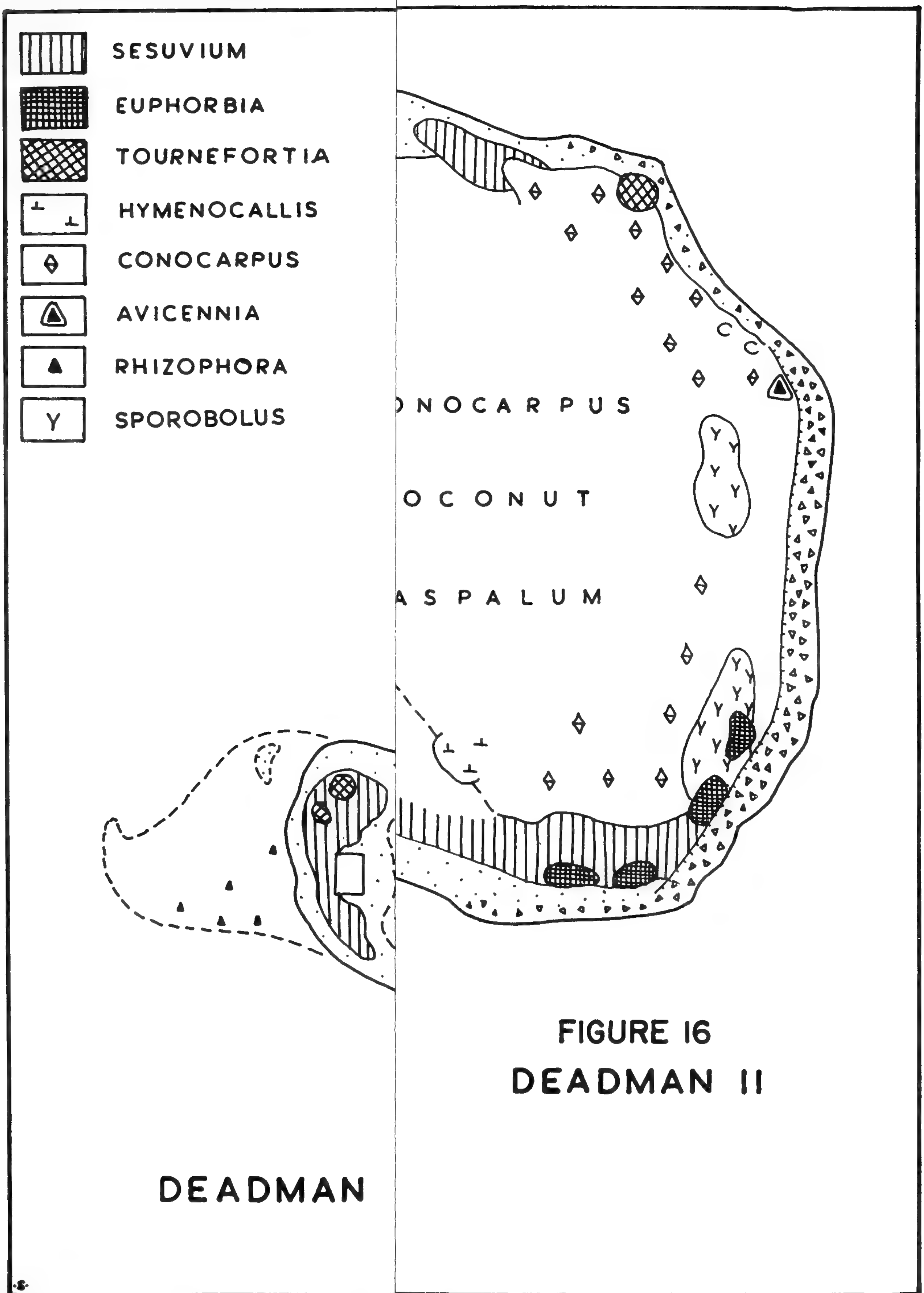


FIGURE 16
DEADMAN II

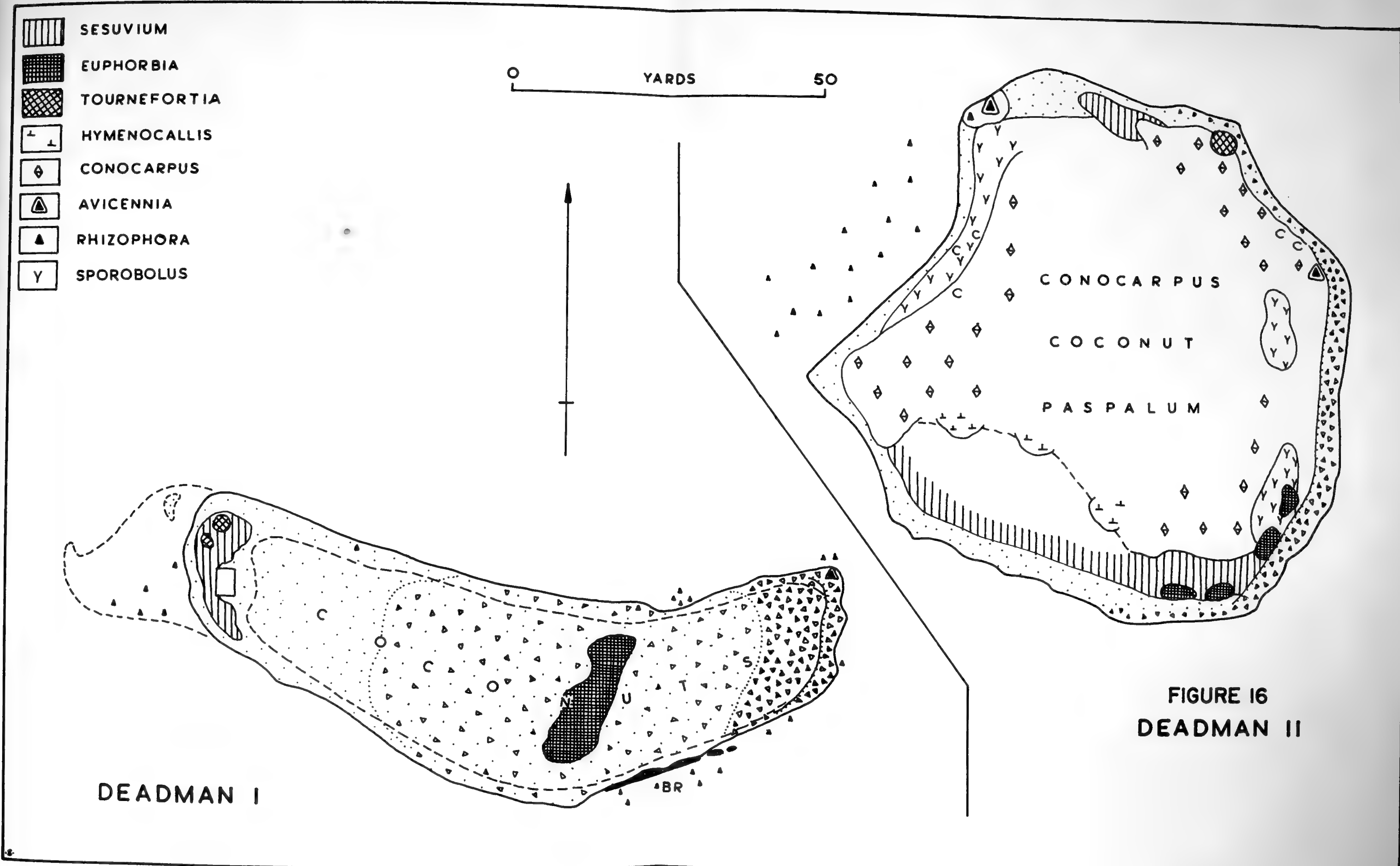
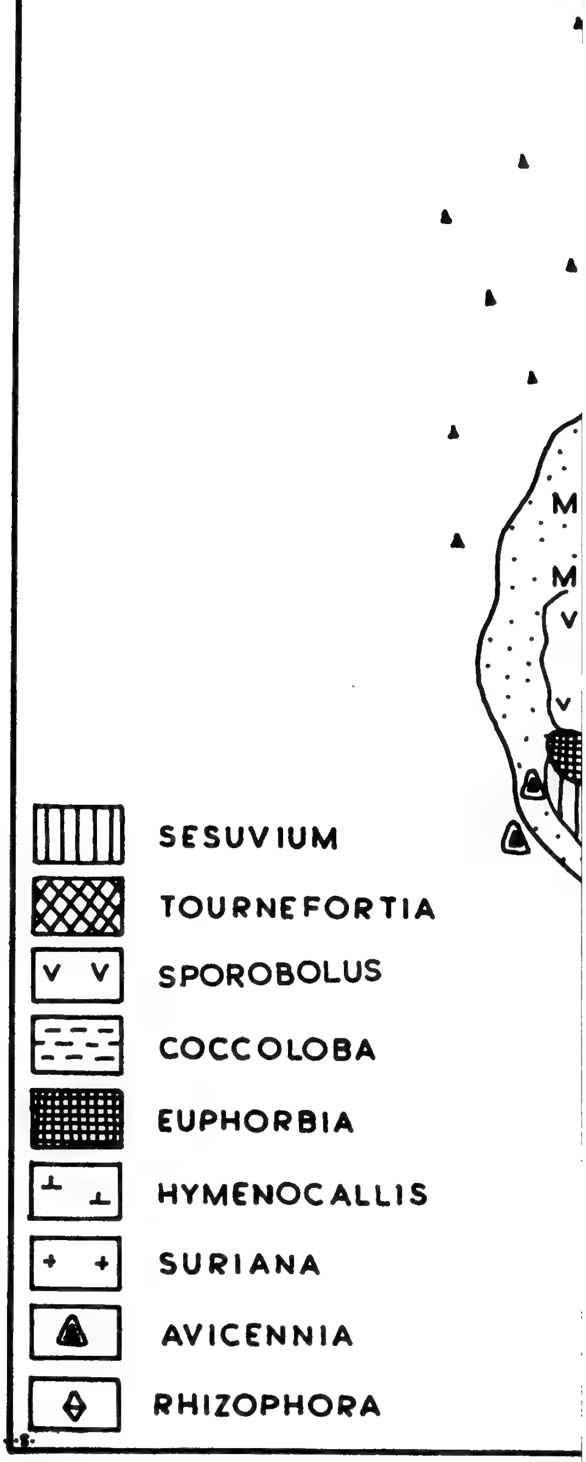


FIGURE 16
DEADMAN II

FIGURE 17
DEADMAN IV



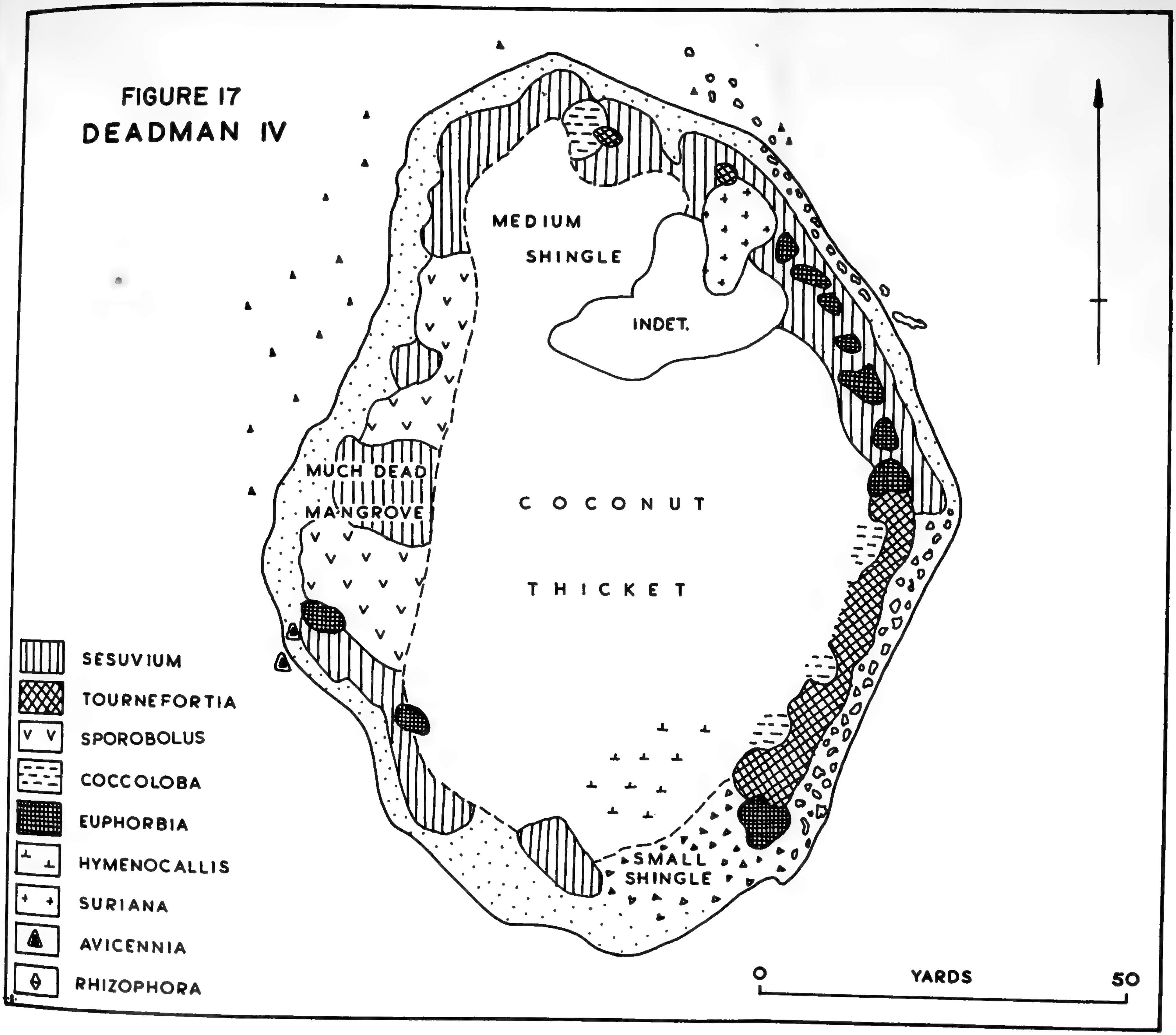


FIGURE 17
DEADMAN IV
MEDIUM SHINGLE
INDET.
MUCH DEAD MANGROVE
COCONUT THICKET
SMALL SHINGLE
SESUVIUM
TOURNEFORTIA
SPOROBOLUS
COCCOLOBA
EUPHORBIA
HYMENOCALLIS
SURIANA
AVICENNIA
RHIZOPHORA
0
YARDS
50

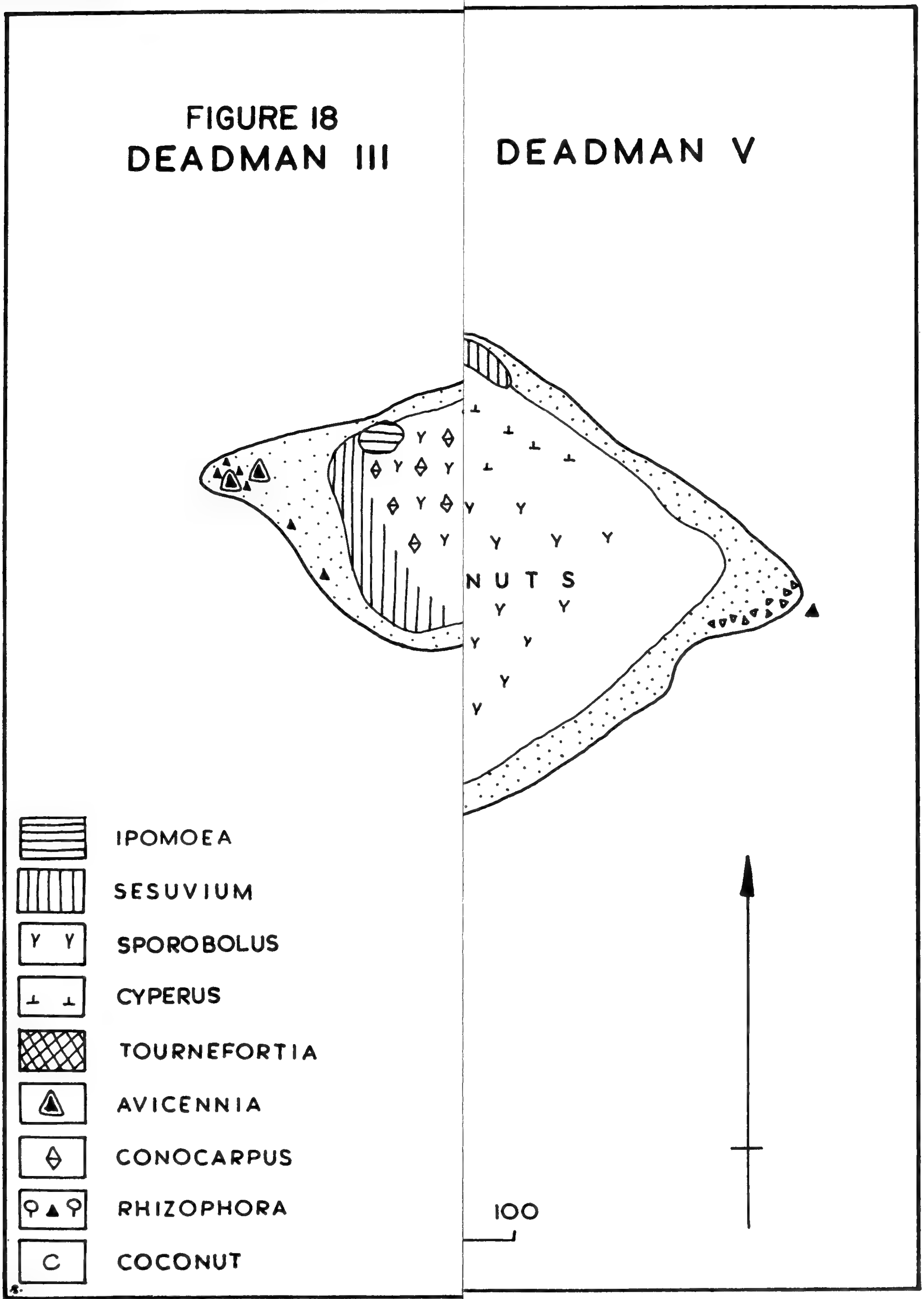


FIGURE 18
DEADMAN III
DEADMAN V
NUTS
IPOMOEA
SESUVIUM
SPOROBOLUS
CYPERUS
TOURNEFORTIA
AVICENNIA
CONOCARPUS
RHIZOPHORA
COCONUT
100

FIGURE 18

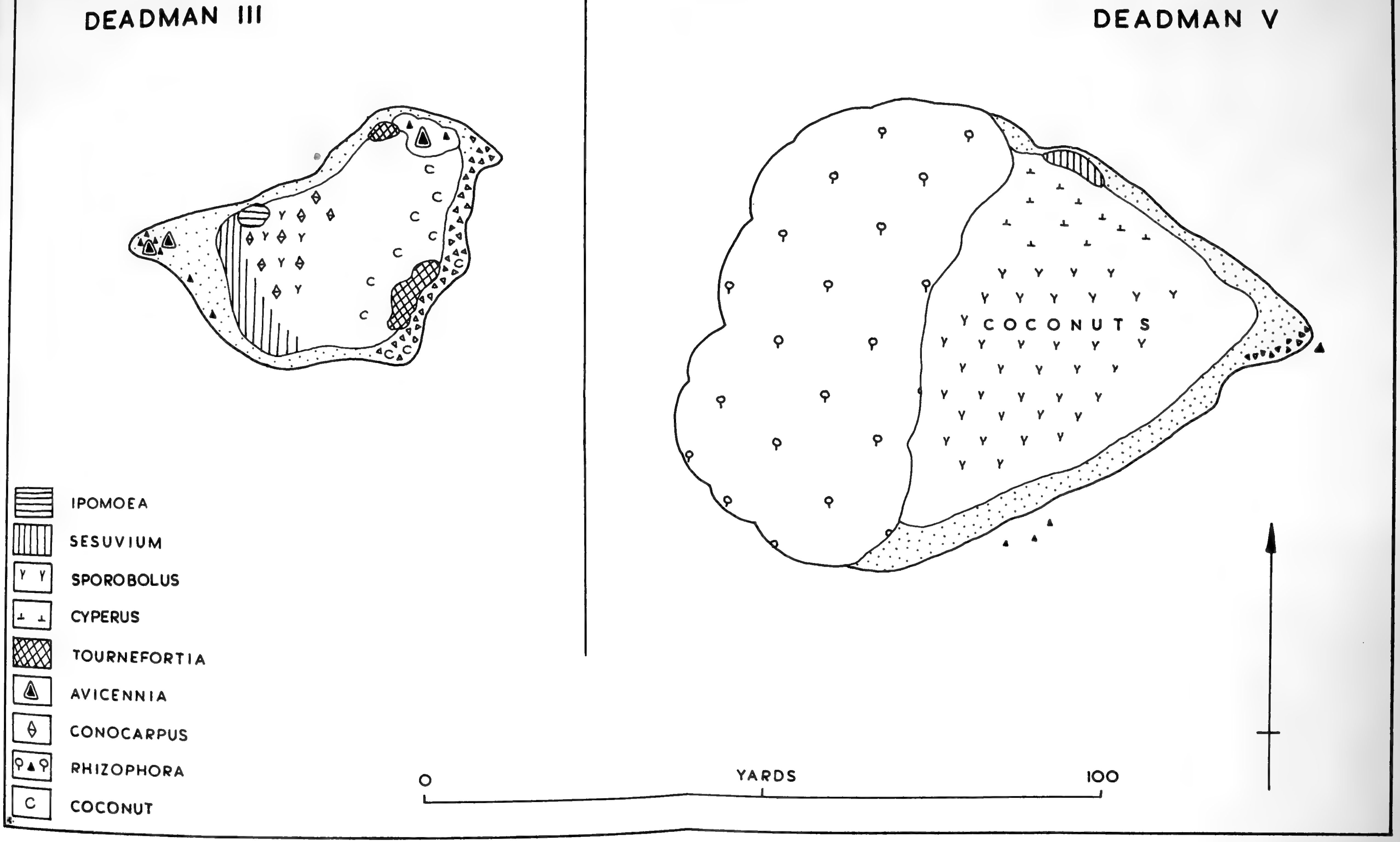

DEADMAN III
DEADMAN V
COCONUTS
IPOMOEA
SESUVIUM
SPOROBOLUS
CYPERUS
TOURNEFORTIA
AVICENNIA
CONOCARPUS
RHIZOPHORA
COCONUT
0
YARDS
100

FIGURE 19

LITTLE CALABAS

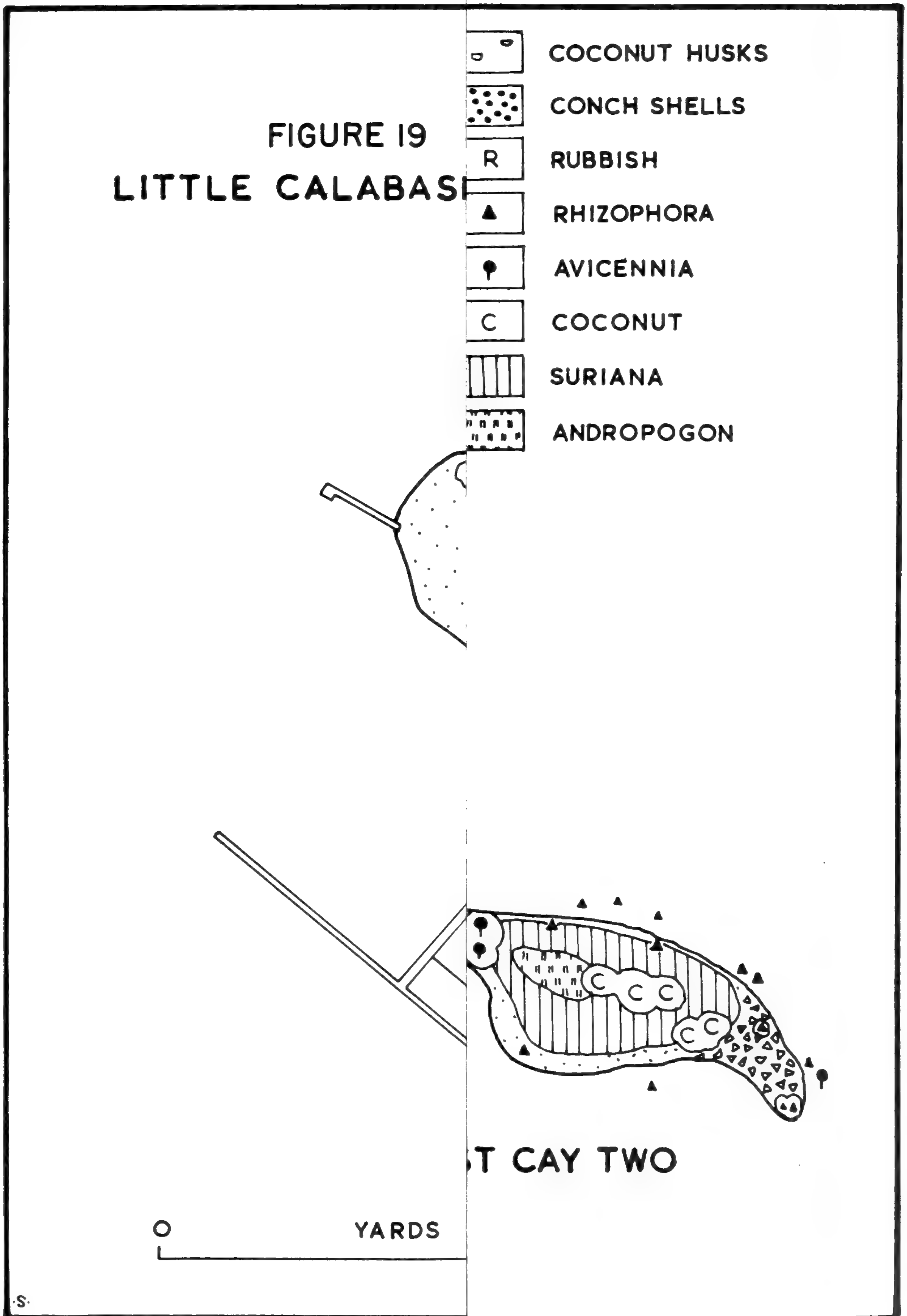
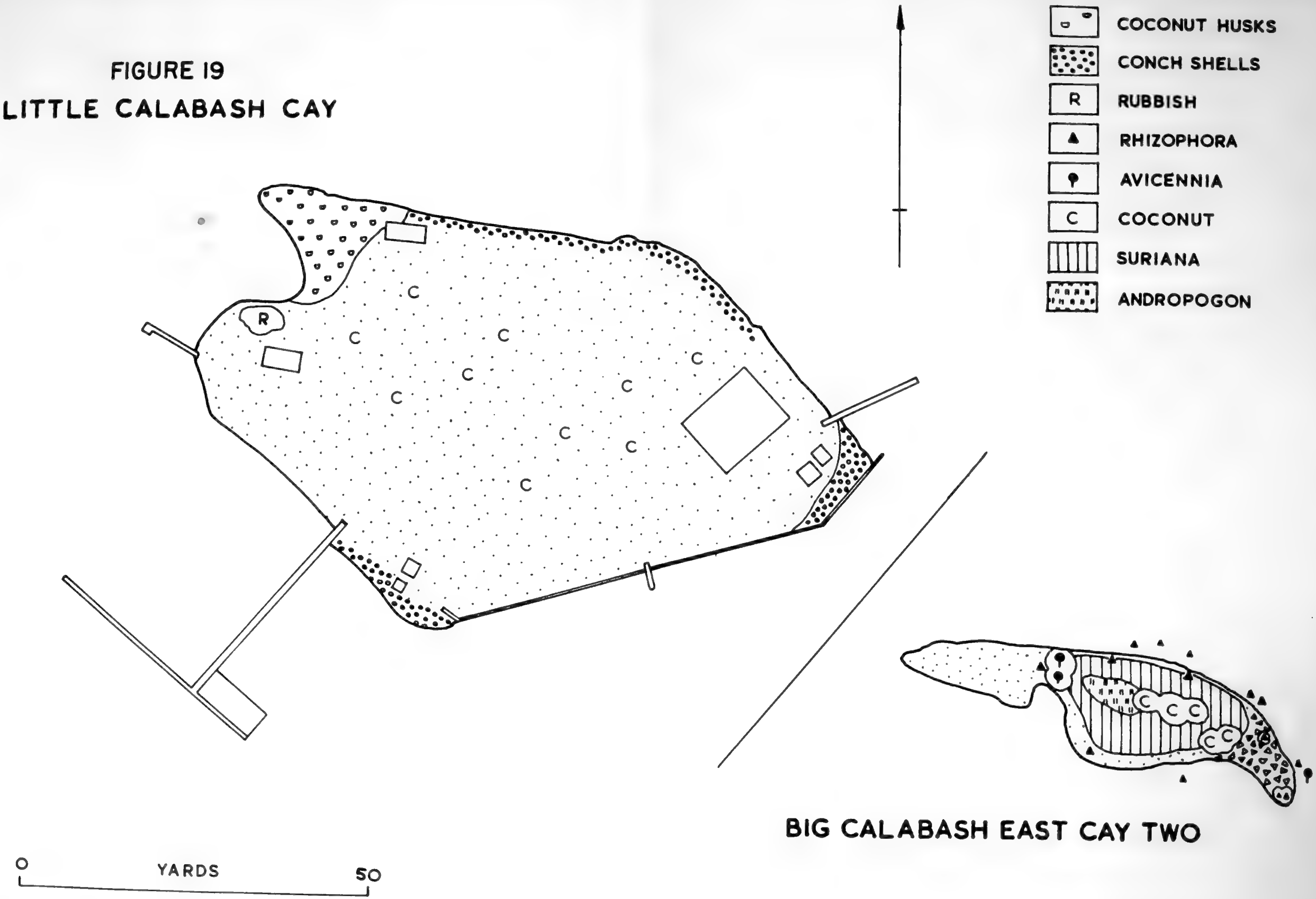
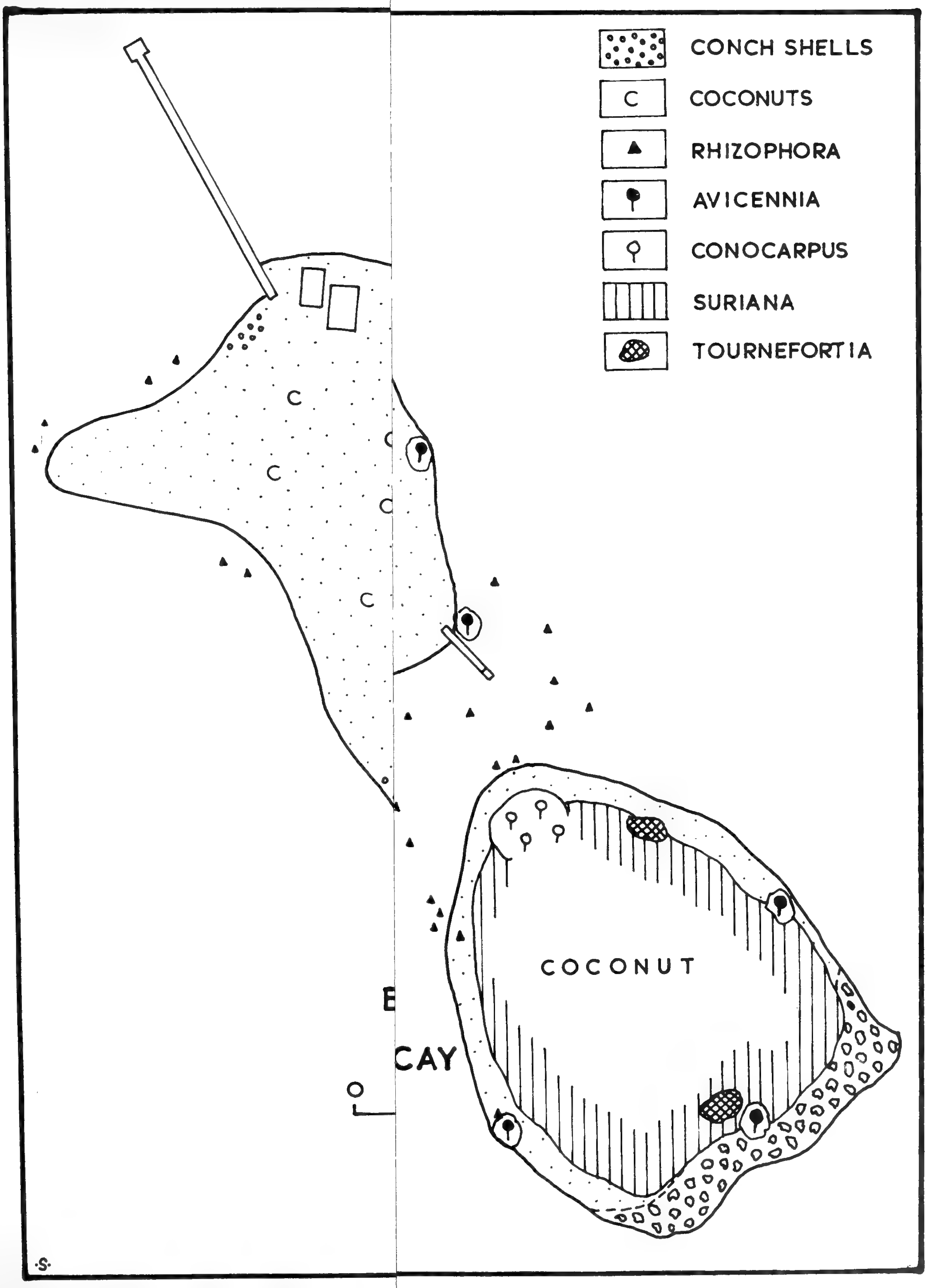


FIGURE 19

LITTLE CALABASH CAY




CONCH SHELLS
C
COCONUTS
RHIZOPHORA
AVICENNIA
CONOCARPUS
SURIANA
TOURNEFORTIA
C
C
C
C
C
COCONUT
CAY
O
·S·

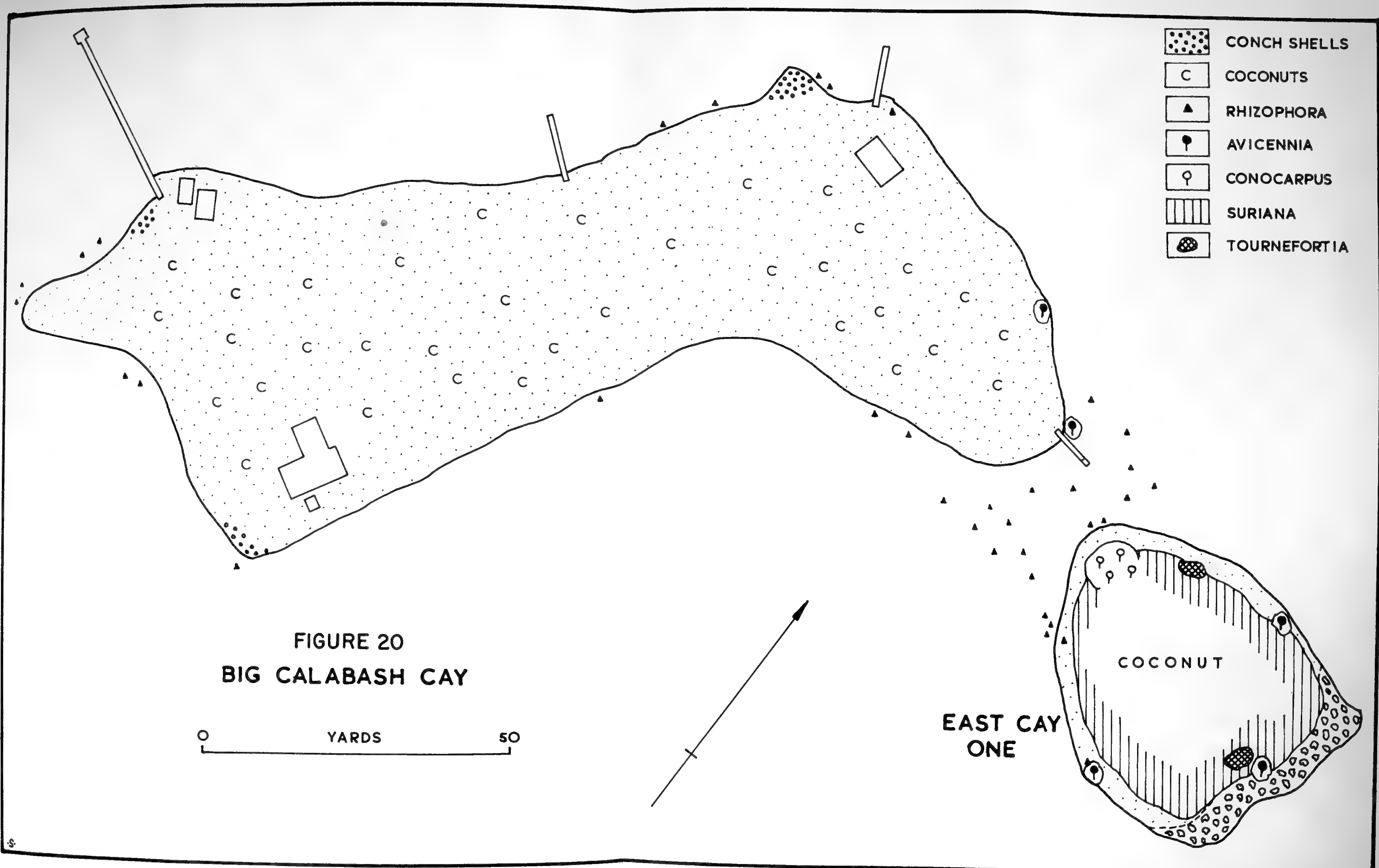


FIGURE 20
BIG CALABASH CAY

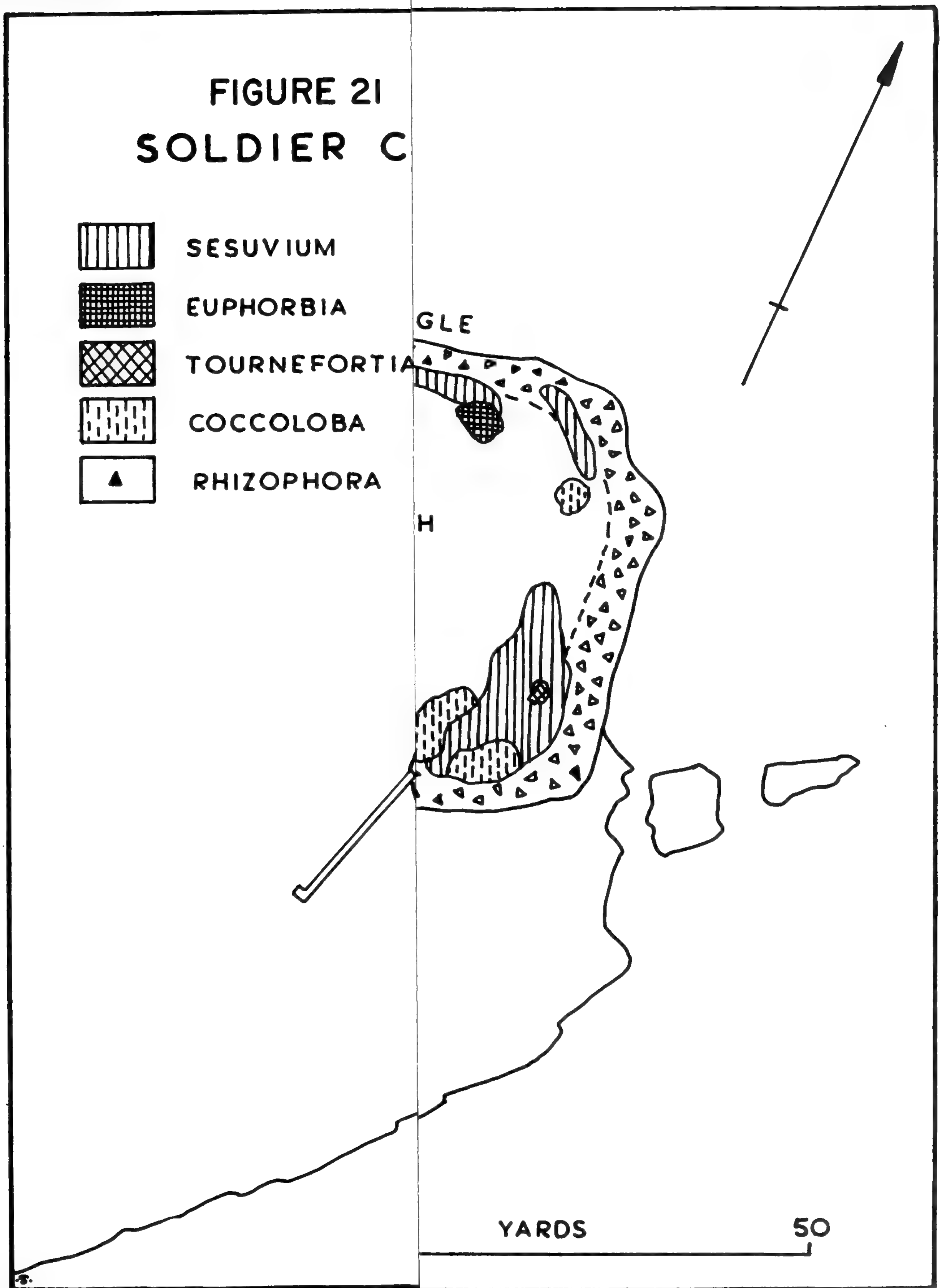


FIGURE 21
SOLDIER C

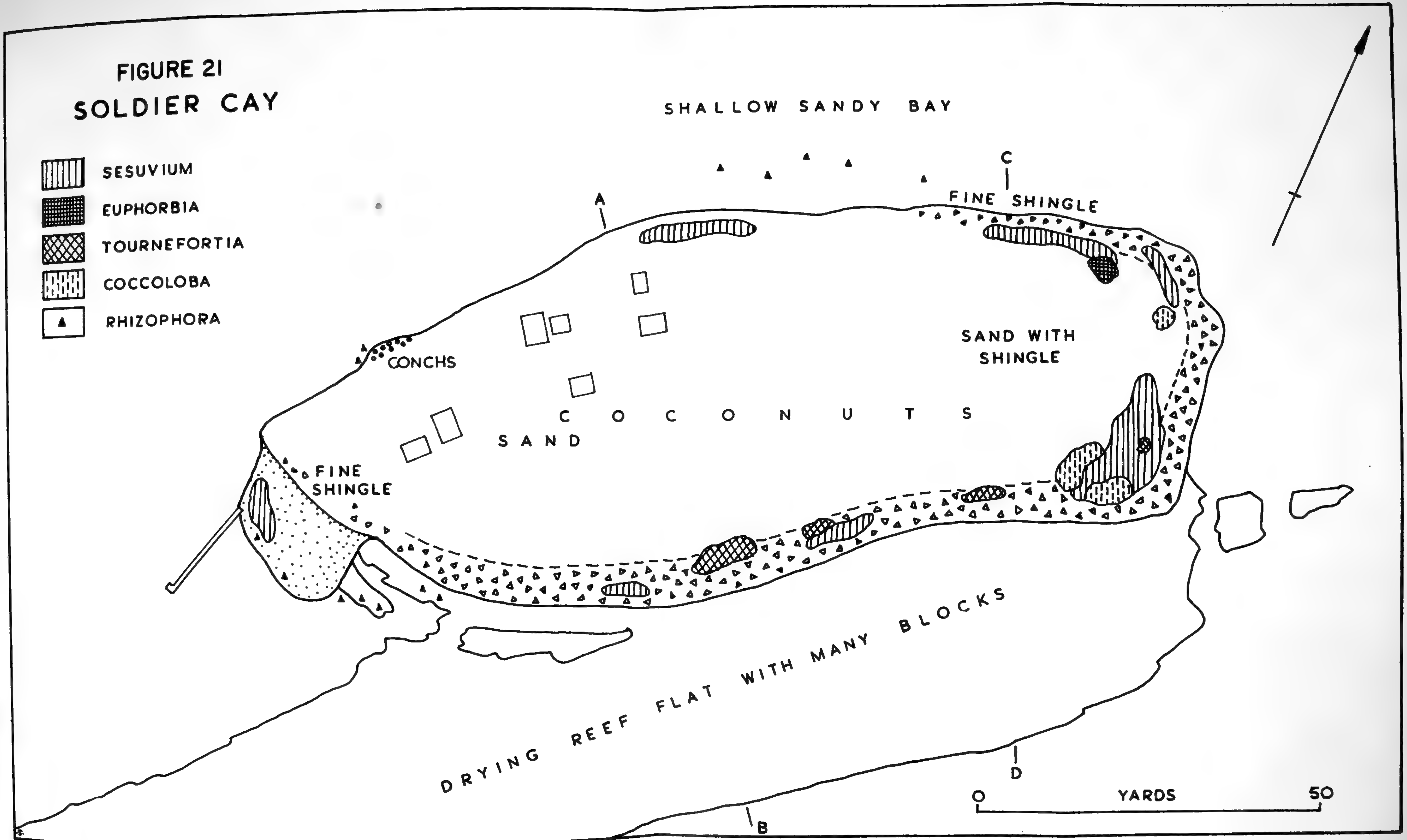


FIGURE 21
SOLDIER CAY
SESUVIUM
EUPHORBIA
TOURNEFORTIA
COCCOLOBA
RHIZOPHORA
SHALLOW SANDY BAY
A
C
FINE SHINGLE
CONCHS
SAND WITH SHINGLE
COCONUTS
SAND
FINE SHINGLE
DRYING REEF FLAT WITH MANY BLOCKS
D
B
0
YARDS
50

FIGURE

SOLDIER

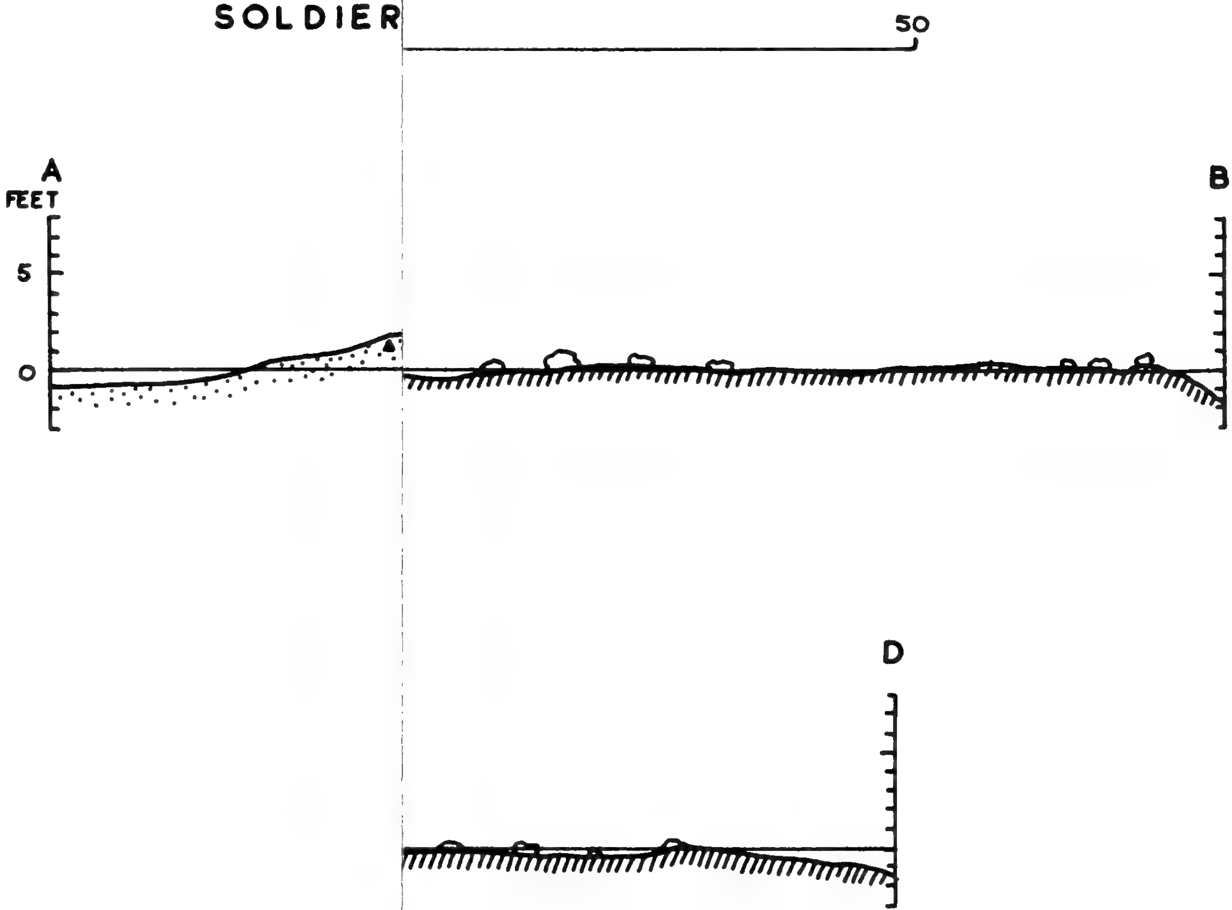
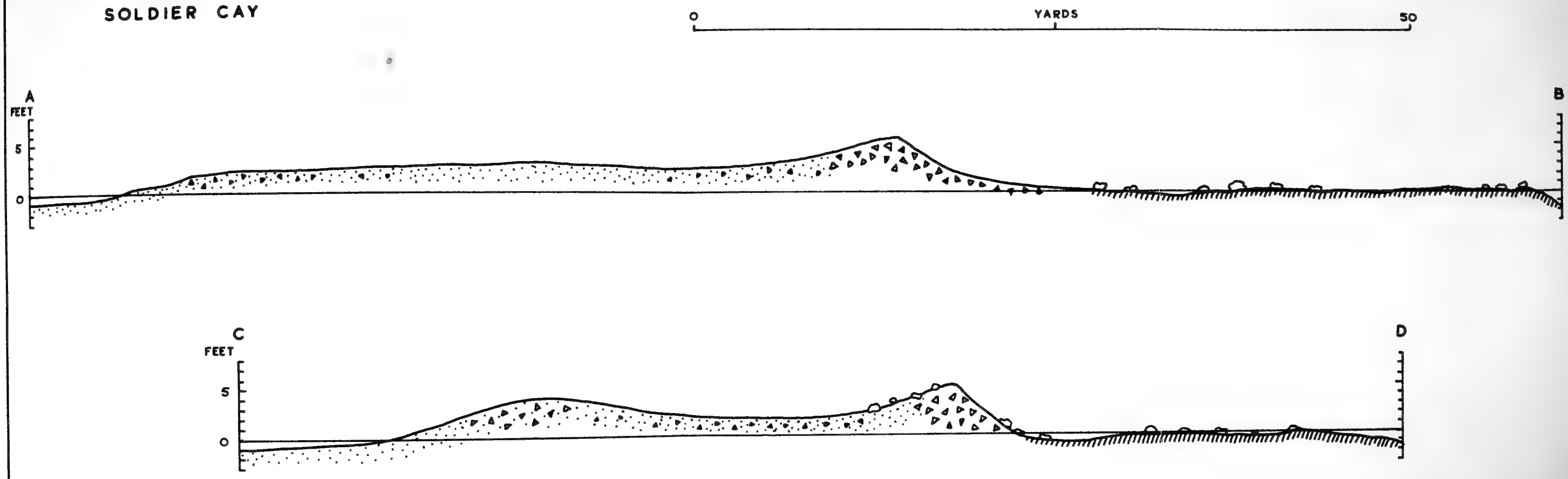
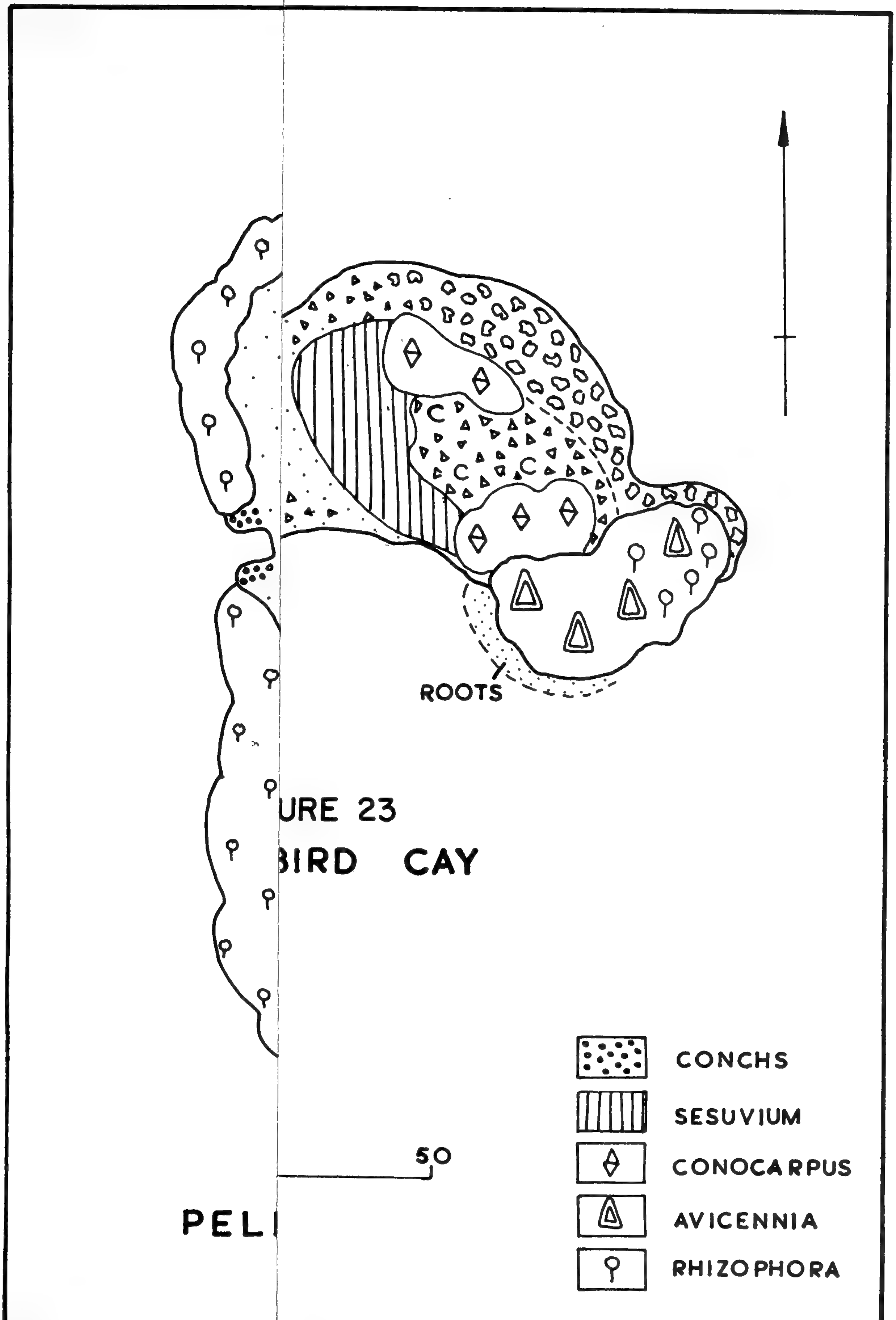


FIGURE 22
SOLDIER CAY





ROOTS
URE 23
IRD CAY
50
PEL
CONCHS
SESUVIUM
CONOCARPUS
AVICENNIA
RHIZOPHORA

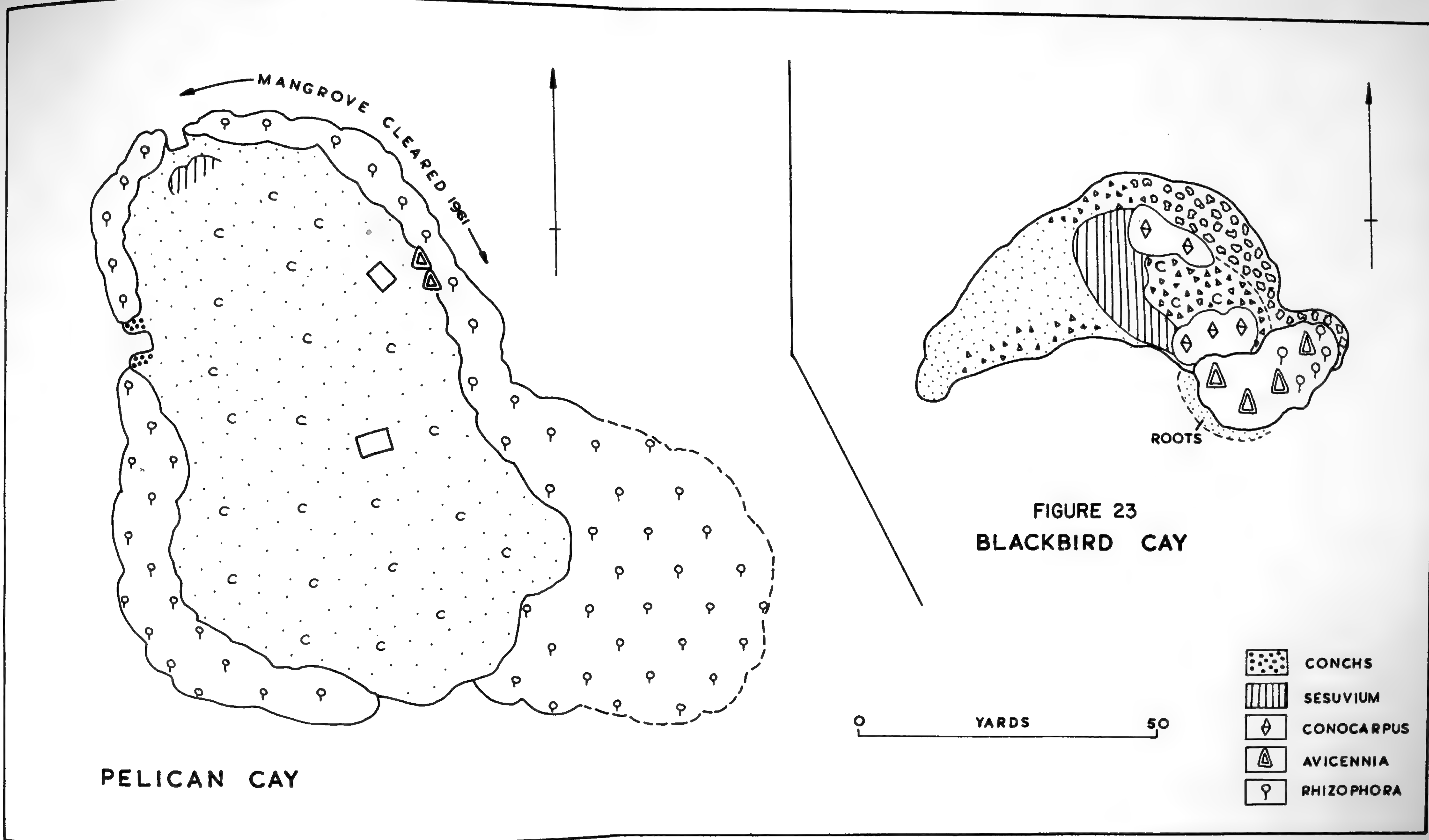
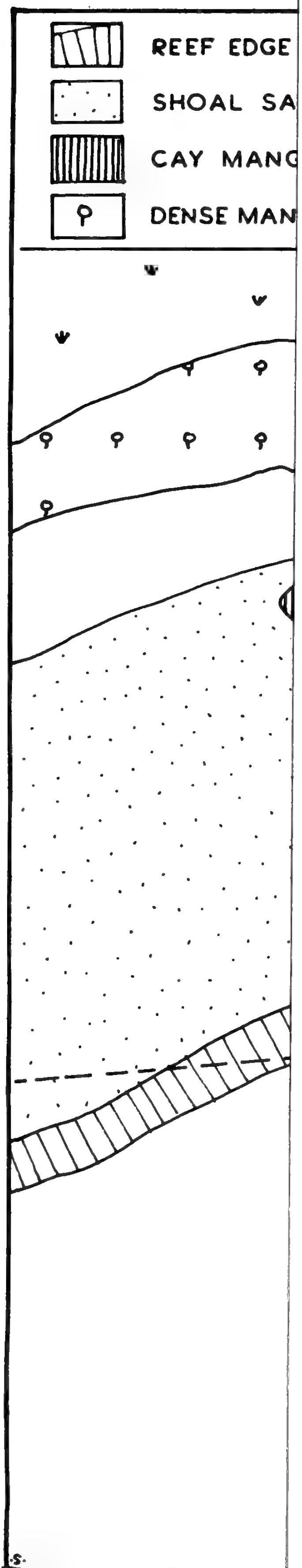

MANGROVE CLEARED 1961
ROOTS
BLACKBIRD CAY
YARDS
0
50
CONCHS
SESUVIUM
CONOCARPUS
AVICENNIA
RHIZOPHORA
PELICAN CAY

FIGURE 23


REEF EDGE
SHOAL SA
CAY MANG
DENSE MAN

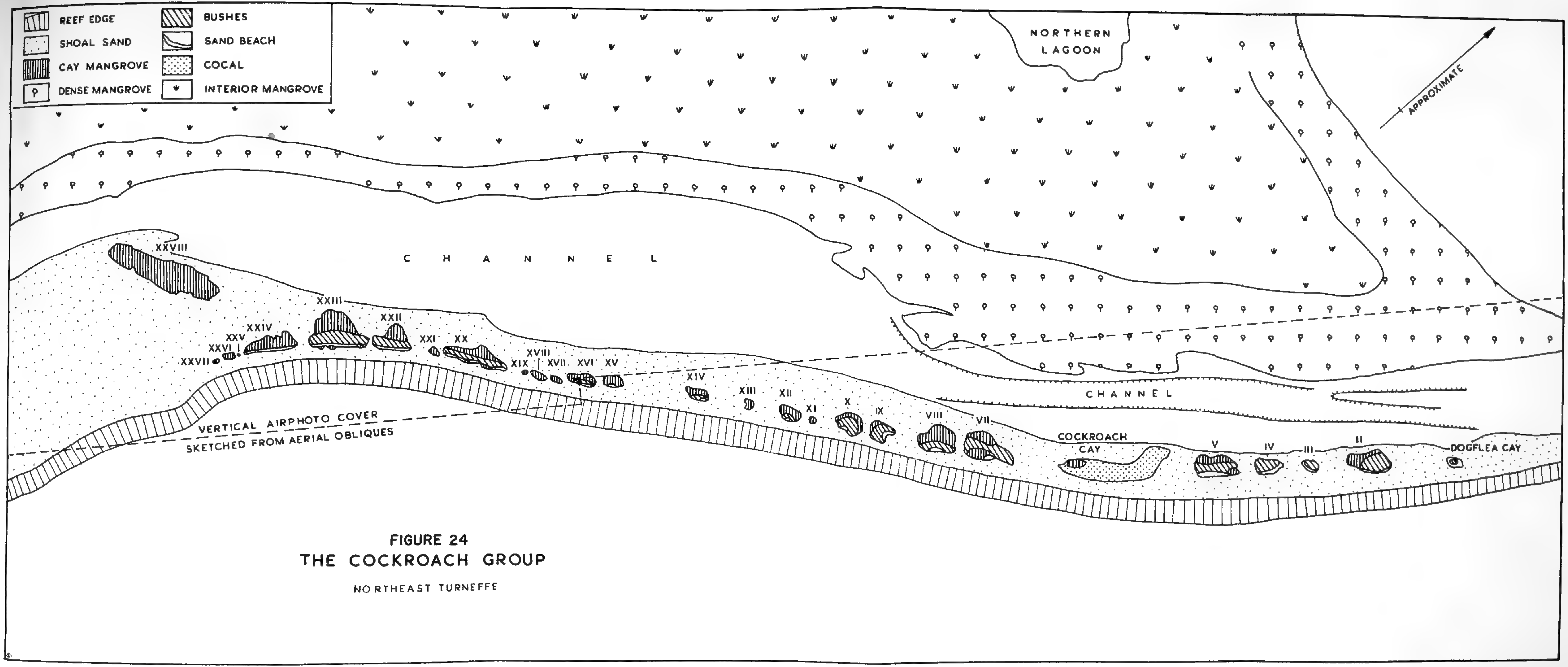


FIGURE 24
THE COCKROACH GROUP

NORTHEAST TURNEFFE

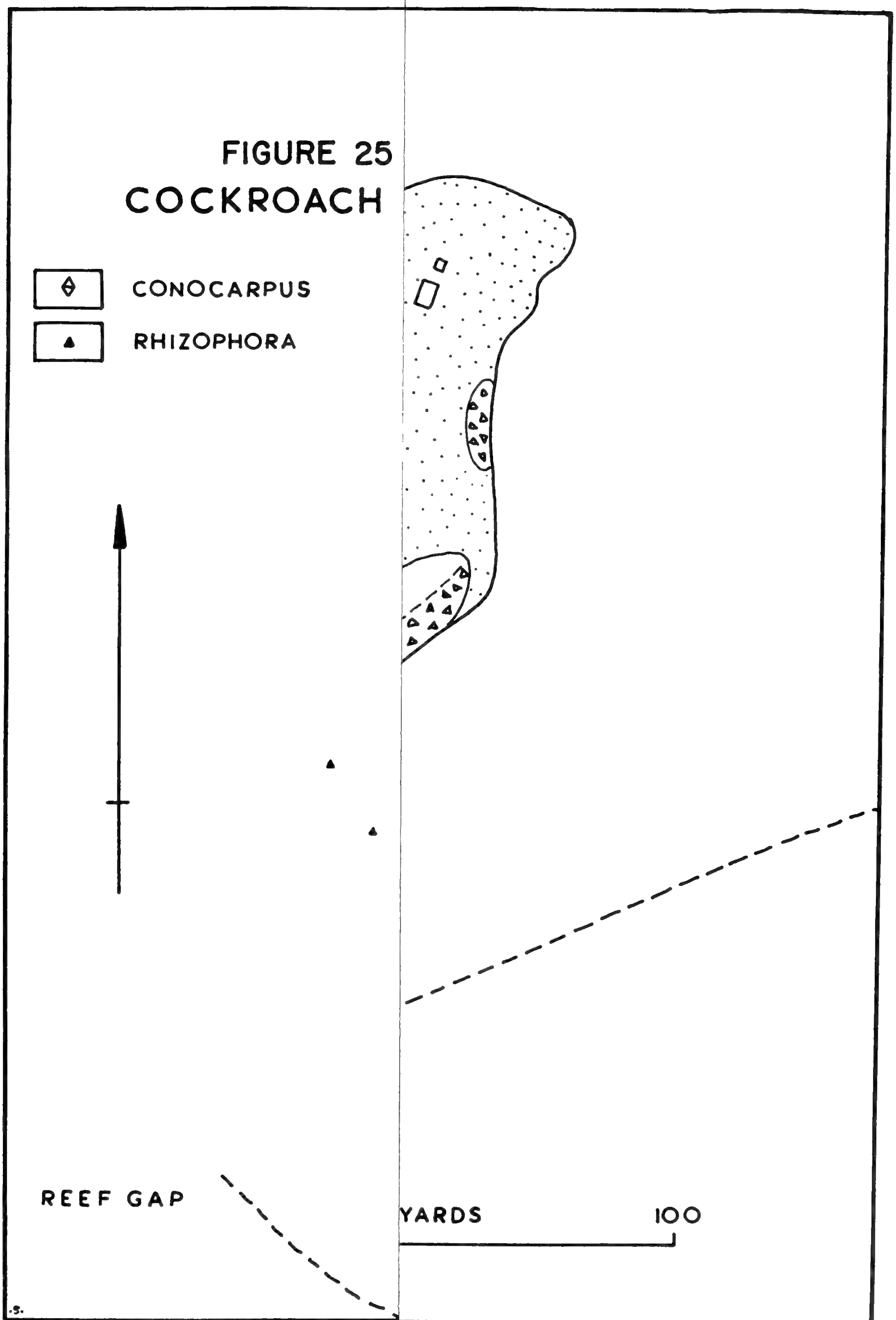


FIGURE 25
COCKROACH
CONOCARPUS
RHIZOPHORA
REEF GAP
YARDS
100

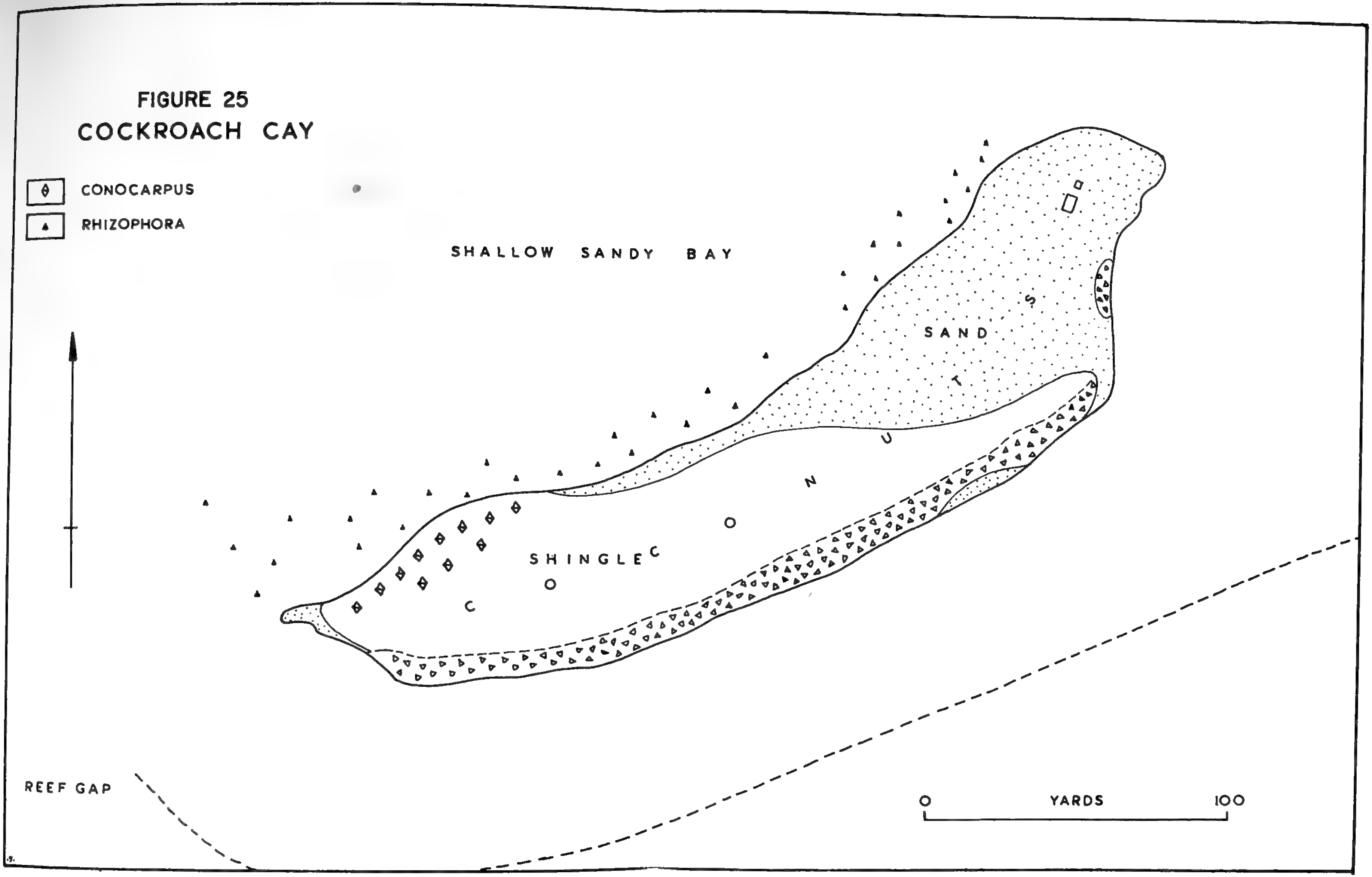


FIGURE 25
COCKROACH CAY
CONOCARPUS
RHIZOPHORA
SHALLOW SANDY BAY
SAND
S
T
U
N
O
C
SHINGLE
O
C
REEF GAP
0
YARDS
100

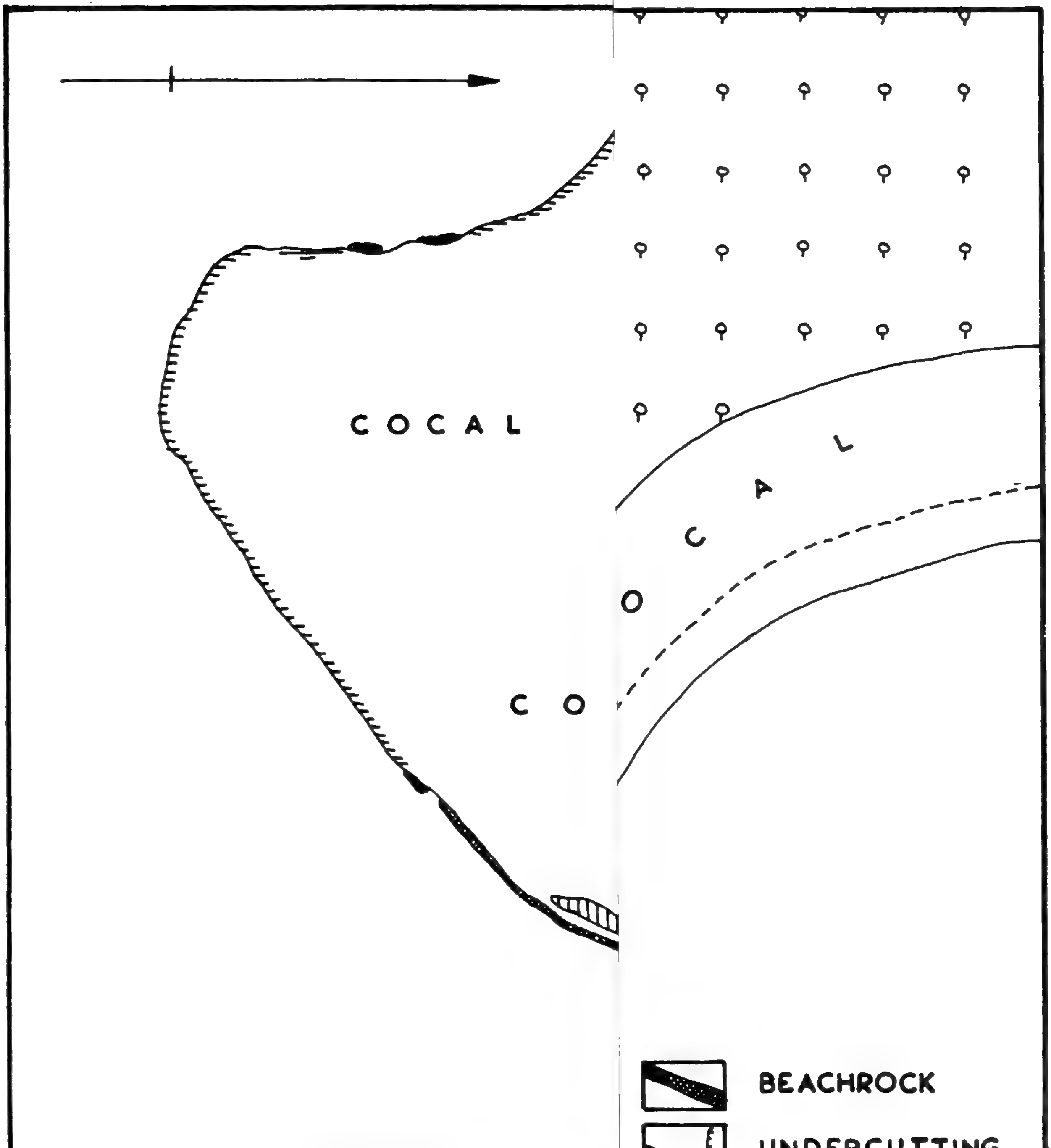


FIGURE 26
HARRY JONES POI

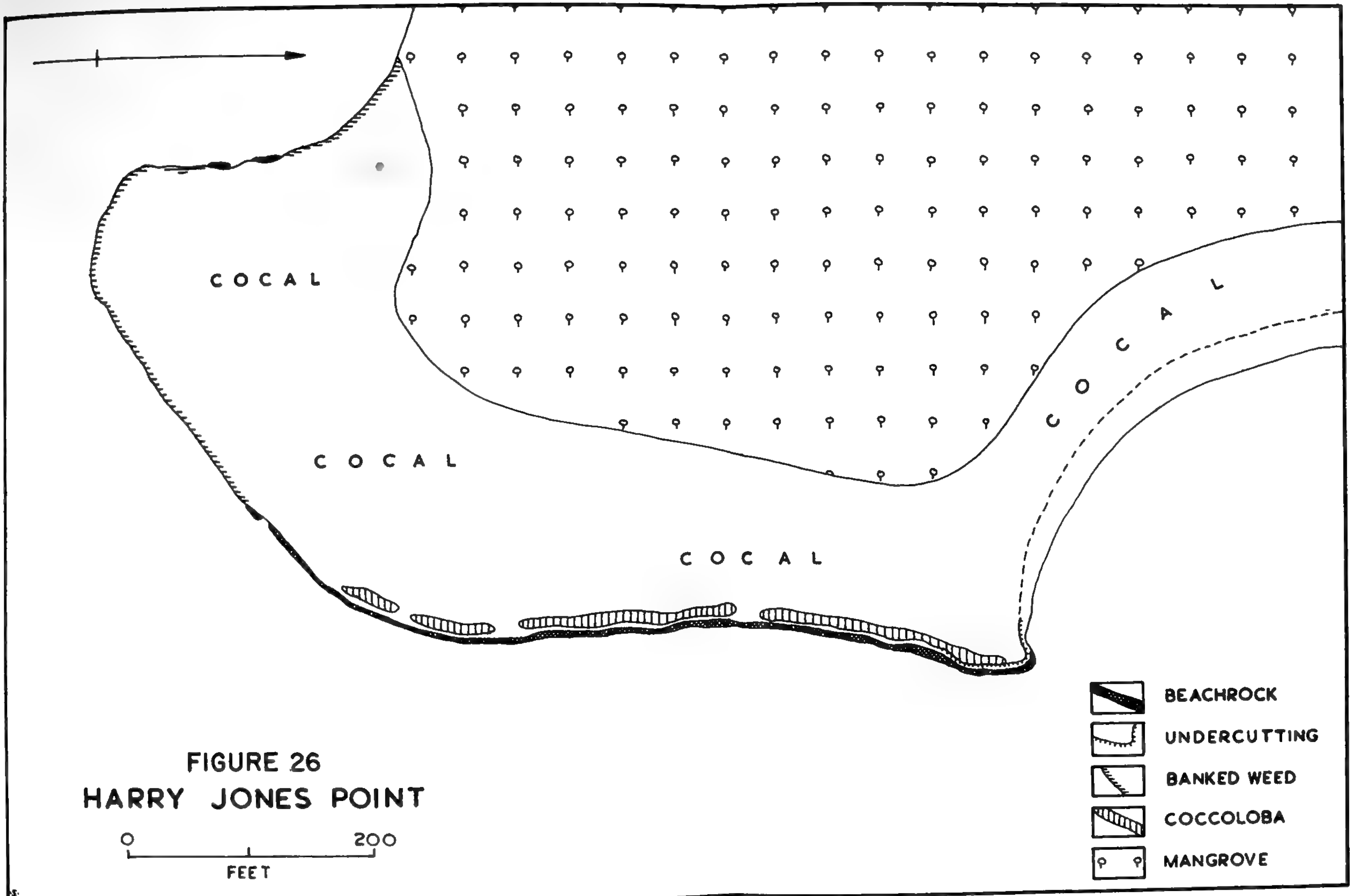


FIGURE 26
HARRY JONES POINT

VI. LIGHTHOUSE REEF

Lighthouse Reef (cf. Vermeer, 1959, 18-19, 95-103), with an overall length of 25 miles, width of $4\frac{1}{2}$ miles, and approximate area of 78.5 square miles, is the smallest of the three atolls in area (though longer than Glover's Reef), and the most irregular in outline (fig. 27). The main part of the atoll measures some 17 miles in length, and to the southwest corner of this is appended an arc-shaped reef segment some 8 miles long and only 2 miles wide. The cause of this great southeastern bight between Half Moon Cay and the south end of the atoll is not known, but the suggestion made by Fairbridge (1950) that similar irregularities on Pacific atoll rims may result from submarine slumping could apply here, especially in view of the great depths off the east reefs near Half Moon Cay. Published charts of the atoll are extremely rudimentary, and the airphoto cover only extends to some two-thirds of the atoll area, so that our knowledge of the gross features of the reef and lagoon is incomplete.

Lighthouse Reef is surrounded by a well-developed reef-rim, with only three major gaps: one at the north end, giving access to Sandbore and Northern Cays; another west of Half Moon Cay, along the north side of Southeast Bight; and the third and largest on the west side of the atoll, immediately north of Long Cay. These never carry more than 1-2 fathoms water and are interrupted by scattered coral heads. In addition it is possible for small boats (maximum draught 5 feet) to cross the western reef at several points by threading between the coral colonies; but local knowledge is required for this.

The eastern reefs are remarkable for the breadth of the zone of living reef and the breadth of the reef-flat. The outer edge of the reef is shallowly sinuous in plan, and steep-to; it is lined by a well-developed groove-and-buttress system similar to that reported in Jamaica by Goreau (1958) and on exposed reefs in many parts of the Pacific (e.g. Emery, Tracey and Ladd, 1954; Munk and Sargent, 1954; Newell, 1956). The average width of the windward reef-flat, from air photographs, varies from 1,000 to 2,000 yards, and averages 1200-1500 yards. The width of the zone of living reef on the outer edge of the reef flat averages 500 yards. As was seen in transect B, much of this area consists of a submerged pavement of encrusting and loose nodular Lithothamnion, with only sparse growth of stony corals. Seaward of the algal pavement the dominant coral is massive Acropora palmata on the seaward slope, and lagoonward, Montastrea annularis on the reef-flat. The east reefs are continually pounded by surf, and the reefs are further remarkable in the strength of the current continually flowing across the reef-flat under the influence of prevailing winds and waves. This is estimated at 2-3 knots, and locally possibly more, and is so powerful that it is impossible in many places to swim against it; it may indicate the existence of a higher sea-level outside the reefs than in the lagoon. No such current is experienced on the windward reefs of Turneffe, though the drift there is also westwards.

The reef-flat forms a broad shoal area carrying as much as 5-10 feet of water. From the air and from the sea it is seen as a broad swath of translucent green water, in sharp contrast with the ultramarine

of the sea beyond. It consists for the most part of loose detrital sands, with much algal and foraminiferal material. The air photographs show submerged sand ripples on this flat, especially north of Saddle Cay, and on the west side of the southeast bight, aligned transversely to prevailing winds, generally about 1,000 yards long and 2-300 yards apart. These were seen from the air in 1961, but no opportunity arose to inspect them under water. They are quite invisible from the sea, and may, even in shallow water, be crossed without being noticed. They appear very similar to the much more striking ripple formations of the Bahama Banks (Rich 1948; Newell and others, 1951; Newell and Rigby 1957). Ripples are also well-developed on the barrier reef flat between Cay Glory and Gladden Spit. So far as is known, reef-flat ripples have not received much attention in previous atoll or barrier reef studies, perhaps because most Pacific atolls are too exposed to permit their formation on reef-flats. Hence such ripples may be restricted to more sheltered atolls and reefs, and it would be interesting to see whether they are developed on the atoll reef-flats of the easternmost East Indies.

The somewhat anomalous location of Saddle Cay on the inner edge of the eastern reef-flat deserves notice.

The western, leeward flats and reefs are of a quite different character. Towards the north end of the atoll, the western reefs are backed by great lobe-shaped accumulations of barren white sand up to 1,000 yards in width, the living reef forming an extremely narrow fringe. Transect E was in such an area. Farther south the sand lobes disappear, and the narrow reef fringes a shallow reef flat 4-8 feet deep, which merges almost imperceptibly into the lagoon floor. Groove-and-buttress systems are not developed on these reefs, except in the extreme north, west of Northern Cay.

The lagoon enclosed by the two reefs is of unequal depth, and is generally shallower on the west side, where it grades into the reef flat, and deepens eastwards; the slope from the eastern reef-flat to the lagoon floor is steep and well-defined. No systematic sounding has been carried out since Owen recorded depths of 1-2 fathoms between the Long Cay reef-gap and Half Moon Cay, but it can be stated that the average depth of the lagoon on the east side of the atoll is 2-3 fathoms. On the west side it is shallower, and averages 1-1½ fathoms. These differences in depth can be clearly seen on the air photographs (e.g. CAE-6-186), where the shallow western sector appears to end fairly abruptly along a north-south line in the middle of the lagoon, the junction being fringed with patch-reefs. This feature is known locally as "Middle Reef", and certainly extends some distance north of the area covered by air photographs. Numerous small patch-reefs rise to the surface from the shallow western sector of the lagoon floor; those that rise from the deeper floor to the east are larger, more widely spaced, and better defined. They do not, however, approach the density of patches in the Glover's Reef lagoon. According to reliable local informants the maximum depth of the whole lagoon is found on the east side some 8-9 miles north of Half Moon Cay, where the bottom carries 4½-5 fathoms water.

Perhaps the most remarkable feature of the Lighthouse Reef lagoon is the deep depression in the lagoon floor 4 miles north of Saddle Cay and some 2200 yards from the eastern reef edge. This is shown on air-photograph CAE-6-186: it is a perfectly round, reputedly bottomless pit, rimmed by living coral, known locally as the "Blue Hole". The reef-rim is most extensive on the southeast side, and on the south and southwest; there are two small gaps on the north side, giving access to the hole itself, which has a diameter of 500-600 yards. The surrounding reef consists mainly of Montastrea annularis, with one or two colonies of Acropora palmata on its inner edge. Other corals present include Agaricia agaricites, Porites astreoides, Mycetophyllia lamarckana and Isophyllastrea rigida. No Acropora cervicornis or finger Porites was seen. The reef-rim rises to sea-level, and the two reef-gaps carry $2\frac{1}{2}$ fathoms water. Two leadline soundings were made in the Blue Hole, one of 464 feet, the other of 472 feet. The first brought up a little very fine calcareous mud, impalpable, creamy-grey in colour, and smelling strongly of hydrogen sulphide, thus suggesting conditions of restricted circulation in the depths. Attempts to obtain large samples with improvised equipment failed.

The most reasonable explanation of this feature is that it is a subaerially eroded sinkhole cut in limestones during a period of karst erosion in the time of glacial low sea-levels (cf. Pearse, Creaser and Hall, 1936). The fact that only a single instance is known from all three outer banks is disturbing for this hypothesis, especially in view of the size and depth of the single instance known. Similar depressions, known as "ocean holes", have long been known, and thus interpreted, in the Bahamas (Agassiz, 1894, 42; Newell and Rigby, 1957, 28), and others have been recently described by Jordan (1954) from the Florida Straits. Doran (1955, 10-12, Map 3) has detailed their occurrence in clusters in the Bight of Acklins, Southeast Bahamas. Here 17 holes have depths ranging from 11 to 198 feet, and areal dimensions of from 20 to 285 feet: all of them much smaller than that on Lighthouse Reef. Doran has described another hole, however, (ibid. 12, Map 11), located south of Grand Caicos, which is "round and about half a mile in diameter, its depth is unknown but greater than 100 feet. This hole is many times greater than others described in the literature and is strangely symmetrical in plan. Although probably also due to subaerial erosion it does not fall into the same pattern as all other ocean holes." The Grand Caicos hole seems very similar to the Blue Hole. I have not been able to discover references to similar holes in Pacific atoll lagoons, though deep depressions of less regular outline do in fact occur, for example on Clipperton almost-atoll (M.-H. Sachet 1962). The term "ocean hole" is well-established in the literature dealing with the Bahamas, but "blue hole" seems to me preferable: the holes need have nothing to do with the ocean, while the term "blue hole" confers an immediate impression of their most striking characteristic.

Land fauna of Lighthouse Reef

The land fauna of Lighthouse Reef is rather better known than that of the other two atolls, and this is particularly true of the avifauna. Salvin (1864) visited Half Moon Cay, Saddle Cay, and Northern Two Cays

in April and May 1862; Bond (1954) spent a day on Northern Cay in January 1954; while Verner has visited Half Moon Cay twice, and more briefly Northern Two Cays, during his study of the pink-footed booby colony (Verner, unpublished thesis, 1959). In addition to Mr. Verner, now of the University of Washington, Half Moon Cay has been briefly visited by other members of the Museum of Natural Science, Louisiana State University, under Dr. G.W. Lowery, Jr. Verner makes use of unpublished notes on the birds in the Carnegie Museum of Pittsburgh.

Less is known of the other land fauna. Half Moon Cay was visited by the Field Museum Mandel Caribbean Expedition in 1940, which collected the lizards Anolis sagrei Dumeril and Bibron, Anolis allisoni Barbour, Iguana iguana rhinolopha Wiegmann, and Ctenosaura similis Gray (Schmidt, 1941, 492-494). Verner (1959) records A. sagrei, A. allisoni, Iguana, and Ctenosaura, and adds Phyllodactylus sp. Bregazzi again collected the anolids and the two larger lizards in 1960 (Thorpe and Bregazzi, 1960, 29). Schmidt comments on the restricted distribution of A. allisoni, which is not apparently found on the mainland, but is confined to island locations, its next nearest record being in the Bay Islands. Schmidt also draws attention to the local name of "wish-willy" for Ctenosaura similis, which does not seem to be used elsewhere. It may be suggested here that this name derives from the Mosquito (?) word Illishle, for Young (1842, 47), speaking of the cays around Bonacca, Bay Islands, says that "a species of guana, called illishle, is to be found in abundance on every key." I have not been able to trace any other reference to this word. Ctenosaura grows to lengths of 3-4 feet on Half Moon Cay; it is a drab yellow colour, with black bars on its back. Iguana iguana, locally known as "iguana" or "bamboo chicken", is esteemed for its flesh; it grows rather larger than Ctenosaura, and is a drab red colour, with black bars. Local fishermen capture both Ctenosaura and Iguana with the aid of a string noose on the end of a stick, creeping up behind the animal and slipping the noose over its neck. The swimming ability of Iguana, which excited Oviedo's attention (1526, translation 1959, 18), is remarkable.

No snakes are known from Half Moon Cay, and apart from hermit crabs (Verner, 1959, 8), the only other large land animal is the rat, Rattus rattus, common in the wooded eastern part, where it is a serious coconut pest. According to fishermen, this is the main reason why no attempt is made to cultivate fruit trees on the cay, though it is questionable whether they would thrive in the poor soil anyway. It was probably accidentally introduced by shipwreck in the nineteenth century. Rats are also common on Northern Cay. Here Bond (1954, 2) noted "some iguana-like lizards, sooty black, but otherwise like those mentioned above (i.e. Ctenosaura), and a small black lizard, probably of the genus Anolis." Land crabs reach enormous sizes on Northern Cay, and are said to invade the houses when rain threatens. No mention seems to be made in the literature of the crocodiles of the interior lagoon of Northern Cay; they are unique on the atolls, and have not been identified. They are sufficiently numerous to be hunted. The common crocodile of the Belize area is Crocodilus moreletii (Romney and others, 1959, 319).

The birds of Half Moon Cay are famous, and more is said in the description of this cay of the colony of pink-footed boobies, Sula sula sula, first recorded by Salvin, and studied by Verner. Besides the booby,

Verner recorded Fregata magnificens as nesting on Half Moon Cay, and "probably" also Columba leucocephala (bald-pate pigeon) and Crotophaga sulcirostris later in the year; he doubts that other species breed there. A nest with three ospreys (Pandion haliaetus) was seen on Saddle Cay in 1960, and by Bond on Northern Cay in 1954. According to fishermen, the brown pelican, Pelicanus occidentalis, breeds on Hat Cay, but no nests were seen there when that cay was visited in 1961. Salvin saw 40-50 pelicans on Saddle Cay in 1862, and thought they were breeding there.

Verner "recorded 98 species of birds on Half Moon Cay, ... and at least 77 of these were migratory forms. Seventeen of the migratory species were recorded regularly enough to indicate that they winter on or near the cay" (1959, 7). Salvin recorded 10 species from Half Moon, 6 from Saddle Cay, and 3 from Northern Two Cays. Bond in a day's collecting observed 24 species at Northern Cay, of which the most abundant were Fregata magnificens Mathews, Florida caerulea L., Thalasseus maximus maximus Boddaert, Dendroica petechia bryanti Ridgway, Seiurus noveboracensis subsp., and Quiscalus mexicanus mexicanus Gmelin. The hummingbird Anthracothorax prevostii prevostii is recorded from Half Moon Cay by Todd (1942, 294), and according to Bond there is a specimen of the flycatcher Elaenia martinica chinchorrensis Griscom from Half Moon in the British Museum. This species is known elsewhere only from Middle Cay, Glover's Reef, and from Chinchorro Bank.

There are a number of pigs, chickens and dogs on Half Moon Cay, dogs on Long Cay, and pigs, chickens and dogs on Sandbore Cay and Northern Cay. There are no domesticated animals on Hat Cay or Saddle Cay.

The cays of Lighthouse Reef

There are at present six cays on Lighthouse Reef, and no positive indication of the former existence of others. Speer (1771) marks four at the north and four at the south end of the reef, but no subsequent chart confirms this. In addition, in his sailing directions, he describes the existence of five cays at the southern end (1771, 18):

> "When you first make the Southern Four Kays, you will see two Kays bearing about N.W. half N. or N.N.W. The southernmost is a long Kay, called Half Moon Kay; the northernmost is a short Kay, called the N.E. Kay. As you near them you will see a small Kay between these two Kays, and a small Kay to the south end of Half Moon Kay; and some distance to the southward of that Kay, there is a very small round Kay called Hay Kay; and is joined by a Reef to Half Moon Kay."

The Half Moon Kay here referred to is not the cay now so called, but the modern Long Cay (this confusion was noted in Section I). The passage taken literally seems to indicate the existence of a "small Kay" between modern Long Cay and Hat Cay, and if this is so, then it seems most likely that the cay in question is the rounded mangrove appendage at the southern end of Long Cay, the intervening section having been filled with mangroves in the last two centuries. The "N.E. Kay" which Speer refers to is modern Half Moon Cay. Jefferys (1775), in the various editions of his chart, marks "North Two Keys", still so called, including "the

Bushy Spot" (Sandbore Cay) and Tall Trees Key (Northern Cay), and Southern Four Keys. These include "Half Moon Key" (Long Cay), "Easternmost Key" (Half Moon Cay), Hat Cay, and a large cay north of the present Long Cay, termed "North Key". This is presumably modern Saddle Cay. All these were charted by Owen in 1830, and still exist.

These cays vary greatly in size, from Saddle Cay, only a few yards in diameter, to Northern Cay, which covers over $2\frac{1}{4}$ square miles. Northern Cay and Long Cay are large, and have considerable swampy areas; Half Moon Cay is a large sand and shingle cay; and Saddle and Hat Cays are smaller sandy cays with varied vegetation. Vermeer states that "On Lighthouse Reef bank, the other deep sea bank which I visited, only sand cays occurred. In this case, insufficient protection of any part of the bank appears to account for the absence of mangrove cays" (1959, 40). This may apply to Half Moon Cay and Sandbore Cay, but not to the cays of the atoll taken as a whole. Rough calculations based on the detailed maps show that of a total land area on the atoll of rather more than 2,000 acres, less than one-fifth is dry land, and the rest high mangrove swamp, lagoon, and dead and dying mangrove. The percentage of dry land is greatest on the smaller cays, while the greater part of the two largest cays is mangrove swamp. All six cays were visited, some several times, in 1960 and 1961. They are here described, with detailed maps, which in the case of the two large cays have been partly plotted from aerial photographs.

Sandbore Cay

Sandbore Cay (fig. 28) is the most northerly island on Lighthouse Reef, and the smallest of the Northern Two Cays. It is located at the northern end of the long eastern reef, at the Northern Entrance of the lagoon, and is situated at the leeward edge of the reef-flat, about 1,000 yards back from the reef-edge. It is unfortunately obscured by clouds on available air photographs. Salvin visited it in 1862, Verner in 1958, and our party in April, 1960, and July, 1961.

The cay has a more complex shape than usual in the British Honduras sand cays, and this probably results from the speed of water currents sweeping across the reef-flat and refracting through the northern entrance, and the quantity of debris supplied from the exposed eastern reef. In outline, the island consists of two spits extending lagoonward from a "core" at the eastern end; the northernmost spit is short and wide, the southernmost long and narrow. They enclose a lagoon 4-5 feet deep near its mouth, shoaling shoreward, part of which has been enclosed to make a fish trap, thus further restricting circulation. The gross outline of the cay is triangular: the north side of the island, ignoring irregularities, is some 400 yards long, the south shore 500 yards, and the third side of the triangle, formed by the open mouth of the lagoon on the west side, about 300 yards long. The southern spit varies in width from 20 to 65 yards, while the northern spit forms a rectangular block of land some 150 yards square. A third, small peninsula extends into the lagoon from the north side.

The whole island is built of sand, and none of it rises more than three feet above the sea. The greatest elevations are found along the southeast margins of the south shore (3 feet) and the north shore of the north spit (2-3 feet); the rest of the island lies between 1 and $2\frac{1}{2}$ feet above sea-level. A little shingle is found in places on the crest of the south shore sand-ridge, but it is quantitatively of small importance in the build of the cay. The sand is a medium to coarse coral-algal sand, with fine sand and silt round the margins of the lagoon. Beachrock is exposed at two points: one, on the south shore, consists of a single line about 50 yards long and 18 inches wide, dipping slightly seaward, just exposed at low tide, on a very shallow sandy bottom, and difficult to see; the other consists of two, perhaps three, subdued lines of rock at the east end of the cay, both dipping north. Both rocks are moderately well cemented calcarenites forming a rather thin surface layer, and their significance is discussed later.

The vegetation of the cay is of interest, for while Jefferys (1775) called it "the Bushy Spot", and though much has been cleared for coconuts, large areas are still covered by little-disturbed growth, especially on the spits. At the eastern end of the south shore is a tall growth of Suriana maritima and some Avicennia, with an undercover of Euphorbia. Further west along the same shore Tournefortia gnaphalodes, Conocarpus erectus, tall grasses and Euphorbia occupy the ridge crest, and Suriana in particular occurs sporadically right to the end of the spit. Much of the north shore at its eastern end has been cleared, but along the rest Suriana is again dominant, with low Tournefortia bushes along the northwest shore. Suriana is scattered over the interior of the northern spit, but the only other area of high woody vegetation is near the head of the lagoon on its north side, where there is a thicket, mainly of Conocarpus erectus, with some Suriana and Coccoloba uvifera. The Conocarpus reaches a height of 20-25 feet. The rest of the vegetation is in broad view simply distributed. Along the southern spit we find patches of tall grasses, Ipomoea, Euphorbia, and towards the end a large area of Ambrosia hispida, passing seaward into a mixed zone of Ambrosia, Ipomoea and grasses. On the broad northern spit, there is an inner (eastern) zone of Ambrosia, tall grasses such as Andropogon glomeratus, and lower grasses such as Sporobolus virginicus; and in the outer (western) zone, an area in which Andropogon is the dominant member, with some Ambrosia, Ipomoea being locally dominant along the shore. The extent of Ambrosia found here is somewhat unusual on the sand cays.

There is some evidence of erosion and aggradation of the shores of the cay. Thus the eastern part of the north shore is marked by fallen and leaning coconut trees, and slight cliffing extends westwards beneath the Suriana hedge. On the south shore, slight retreat is shown by the beachrock described. The ends of both spits seem to be expanding lagoonward, particularly so in the case of the northern spit. Here the northwestern and western shore is formed by a broad sand beach, 10-20 yards wide, thrown up in concentric ridges, colonised at its inner edge by low, young Tournefortia, and with tendrils of Ipomoea beginning to extend across it. The two prominent "tongues" extending southwards from this spit represent earlier stages in its growth westwards.

The most striking evidence of erosion, however, is at the east end of the cay. Here a lighthouse was built on dry land in 1885. Since that time, the shore has been gradually pushed back until now the base of the lighthouse stands 75-80 yards out from the shore—an average retreat over 75 years of at least a yard a year. How far back from the sand shore of the cay stood the lighthouse when it was built is not known. However, as a result of this retreat a concrete walk was built to connect lighthouse and cay. This extension is 20 yards long, an average retreat, over the last 15 years, of 4 feet per year, or rather faster than the average for 1885-1945 (slightly under a yard a year). The beachrock previously mentioned at the east end of the island, just north of the concrete walk, clearly dates from the last half century. The outline of the now-eroded cay is clearly seen from the top of the lighthouse as an area of shoal sand, marked on the map. There is a hint of more beachrock immediately east of the light, but the waves break with some force on its foundation and further investigation was not possible.

This is the only instance on this coast where the almost universal lagoonward retreat of sand cays can be dated with accuracy. It is noteworthy that on Owen's 1830 MS chart, Sandbore Cay is shown as a long thin island, without any prominent recurved spits or enclosed lagoon, and thus the present outline has probably developed entirely since that time. The retreat of the east shore and progradation of the two western spits would be interesting to observe over a period of years. One may suggest that, while this retreat has been in progress for some considerable time, it may shortly come to an end, for the cay has very nearly reached the lagoonward limit of the reef-flat on which it stands, and will soon have to advance into deeper water. This will at least retard the western extension of the sandspits, and if erosion continues on the east side, then the eastern part of the cay will gradually be pushed further and further onto the remains of the sandspits, the lagoon will disappear, and ultimately the cay itself will be washed off the flat into the lagoon, leaving the solitary lighthouse as its lone memorial. This could well happen within the next 500 years, if present trends continue. This cay, therefore, though by no means a small one compared to other sand cays on the reefs, vividly illustrates the ephemeral nature of the simple accumulations of unconsolidated reef debris, which basically, is all that sand cays are.

Northern Cay

Northern Cay (fig. 29) is by far the largest island on Lighthouse Reef, and though of quite different shape and larger, it has several features of physiography in common with Long Cay, at the southern end of the Reef. With the exceptions of the ornithologists Salvin and Bond, Northern Cay has not been visited by naturalists and has never been described. It has a maximum east-west extent (along its south side) of over 3300 yards, and a maximum north-south extent (toward the east side of the island) of a little over 3,000 yards. The total area of the cay is a little over 7 million square yards (1460 acres or 2¼ square miles);

of this, approximately $1\frac{1}{4}$ million square yards, or a little more than a fifth, is interior lagoon and standing water; approximately 3.8 million square yards, or about three-fifths, is under mangrove and swamp; and the rest, only one fifth of the whole, is dry land, mainly under coconuts.

The north and west sides of the island approach close to the west reef of the atoll, which here trends NE-SW. The reef crest lies at an average distance of 600 yards from the cay, and the reef-flat at its narrowest is still over 400 yards wide. It is shallow and sandy, generally carrying less than half a fathom of water, and very shoal for some distance from the cay. The reef itself is marked by small breaking waves and a number of projecting blocks of dead coral, which serve to locate it accurately from the shore. The reef-facing shore itself consists of a number of broad embayments and promontories, the deepest embayment being the most northerly, where the shore begins to diverge eastwards from the reef. This shore is sandy throughout and overlooks (except in the northern embayment) a broad low intertidal ridge, covered with Thalassia and worm mounds, and exposed at low tide. A similar feature is also found to the south of the island, fringing the mangrove shore. The sand shore itself is so extensive that it will be described in three parts: the western sand shore, the sand shore of the northern embayment, and the eastern sand shore.

The western sand shore, overlooking the drying Thalassia ridge, extends for 2600 yards from the southwest corner of the cay. It is undercut by wave action for almost the whole of its length, thus forming a cliff whose height depends on the height of the cay surface inland from the beach. Near the southwest corner, the cliff is subdued, and the cay surface only 2-3 feet above the sea; the Thalassia ridge in front of the cliff is scattered with small Rhizophora seedlings. As the beach is followed northwards, however, the height of the cliff increases, reaching a maximum of 7-8 feet near the middle of its extent, and not falling below five feet north of this point. The "cliff" is not always an abrupt feature. Generally a beach of fresh soft sand rises gently from low water level to the base of a steeper slope 3-5 yards away; and while the cliff is in places a vertical wall of sand, it is more usually a rounded, subdued feature. It is doubtful whether much erosion is now going on along this sheltered shore, and the cliff at the present time may be a fairly stable feature. The most interesting feature of this shore is its relict beachrock (BR I), intermittently outcropping along it for about 1500 yards. All this beachrock maintains a constant altitude of about 1 foot above low tide level at the base of its outer edge. It varies in thickness from 6-9 inches, and is deeply pitted and eroded. Its surface is blue-black in colour, presumably through algal encrustation, and passes landwards under the cliff sands for an unknown distance. Because of the depth of the overlying sand it was impossible to trench and find out how far it extended. At many places along its outcrop the underlying sands have been sapped away, and broken slabs several feet long lie on the beach. The surface of the rock recalls, on a much smaller scale, the sharp irregular topography of exposed reefrock, such as that on the north Jamaican coast. The rock itself is, for the most part, a well-consolidated calcarenite, ringing to the hammer, but much of the induration is surficial, and the sandstone within rather friable. This is the most

extensive outcrop of beachrock found on the British Honduras coast. Because of its extent, and on account of its slight raised elevation above the sea, the question arises as to whether it is a true intertidal beachrock or a cay sandstone. Most of the outcrops show some dip to seaward, and it is thus thought to be a beachrock, possibly developed during a very slightly higher sea-level than the present (i.e. predating a small uplift of Lighthouse Reef itself).

The sand shores of the northern bay are gentler than those on the west side; cliffing is generally absent on the west side of the bay, and the beach of fresh white sand rises gently to a crest about 7-8 yards from the sea. The nearshore Thalassia ridge is not developed in this bay, but submerged Thalassia and other plants are common on the bay floor. The height of the beach crest varies, but averages 5-6 feet above sea-level. The extensive raised beachrock of the west shore is not found in this bay; the only example of beachrock occurs in a small indentation on the east side of the bay, where it is clearly now in the process of formation. At the head of the indentation, and slightly above low tide level (drying at low tide), is a small area of fine indurated sand some 2 feet long and 1 foot wide, passing landward under beach sands. The induration is superficial, forming a crust of soft beachrock 1-2 inches thick. The layer can be traced under the beachsands for over a foot, where it appears to be rather harder than in the exposed area. The induration is sufficient to hold the layer as a whole together, but once a specimen is broken off, it is difficult to prevent it crumbling. The beachrock has a slight dip to seaward, but less than that of the beach itself.

The east side of this bay, like the west coast, is being undercut. The shore itself bounds on one side a triangular-shaped peninsula, jutting out to the North Point (here so called) of the cay. This peninsula, as will be described, is largely built of dune sands, and the shore cliffing exposes sections of fine, cross-bedded dune-sands, permeated by fine roots, and sufficiently cohesive to maintain a vertical wall as the cliff cuts back. The cliff can be traced as a continuous feature right round the peninsula, but is not everywhere exposed to erosion. In detailed form, the beach consists of a number of cusps of new white sand, alternating with shallow embayments, at the head of which the sea is attacking the cliff. Where the cusps occur the cliff is temporarily protected from wave attack. Its average height in this area is 3-4 feet.

At North Point itself, the cliff seems to have been protected for some time. Several concentric ridges of fresh sand have built out below the cliff (here only $1-1\frac{1}{2}$ feet high), and air photographs show that a broad tongue of sediment extends reefward for some distance from the Point itself. The ridges of new sand are only $1\frac{1}{2}-2$ feet high, though broad, but it is interesting to note that similar ridges form part of the peninsula itself, inland from the line of cliffing, which roughly delineates the vegetated area. At least three distinct concentric ridges can be traced inland from the cliff, and another two seaward from it. The ridges pass landward into the peninsula dune-sands.

The eastern sand shore extends along the eastern side of the northern peninsula, and then southwards for about 1100 yards altogether. In the north the peninsula is low (where built of the concentric ridges), clearly defined by an old cliff line, with a bank of clean white sand forming the present shore. The area immediately to seaward is thickly covered with Thalassia. Further south, beyond the limits of the peninsula, the cay surface lies at a higher level, the shore is cliffed (3-4 feet high) and the beach below it very narrow (2-3 feet wide). Offshore the bottom is very thickly covered with grasses and algae, with many small black snails (Batillaria?); as one moves south, the number of Rhizophora seedlings near the shore increases. There are two areas of beachrock along this section of the coast. BR III occurs just south of the small pier on this side of the island. It consists of three small outcrops of well-cemented sand, 1-2 feet wide, dipping seaward, and just submerged at low tide. The surrounding area is thickly covered with Thalassia, and the beachrock is not easy to see from the shore. The second outcrop, BR IV, is found near the southern limit of the eastern beach, and is remarkably similar to BR I, so extensively exposed on the opposite shore of the island. For a distance of 4-5 yards the rock outcrops in the face of the eroded sand-cliff, 12-15 inches above the sea; it is well-cemented, rings to the hammer, and is much eroded. The exposure is 6-9 inches in thickness. The resemblance between BR I and BR IV is probably significant: and the two are probably of the same age and mode of development. BR IV has no discernible dip, lending support to the cay sandstone explanation of its origin.

Little can be said of the rest of the eastern coast and the whole southern coast of the island, for though they were seen at close quarters on many occasions in 1960 and 1961, they consist wholly of Rhizophora mangle, standing in water 1-2 feet deep. They could not be mapped, and the outline shown on the map of the cay is taken from air photographs CAE-6-199 and 200. At no point on this mangrove coast is any sand beach to be seen, and no landing was made along it; at one point near the southeast corner, two lone coconut trees raise their heads above the mangrove some ten yards from the shore, so that a drying ridge some yards within the mangrove probably separates the sea from the cay interior over much of the mangrove shore. The mangrove is mature, and 20-25 feet high.

Northern Cay covers such a large area that it was impossible to see more than a fraction of its interior in the time available. In particular, no visit was made to the interior lagoons, though they were seen from the air. These are said to be 5-7 feet deep, and can be approached through the mangrove from the east coast with very shallow draught boats (dories), or from the northern sand area. They are inhabited by an unidentified crocodile. Far too little is known also of the interior of the northern sand rim, and its vegetation cover. It has an average width of about 200 yards, reaching a maximum width on the west side of the island of over 400 yards. The whole sand area has been planted at some time, deliberately or naturally, with coconuts, but in recent years little attempt has been made to keep the cocals clean, and ground vegetation proliferates, especially along the west side of the cay remote from the settlement in the northern embayment. The impenetrable tangle of vegetation combines with a large number of biting sandflies to restrict access to

the interior. On the cleared, low-lying areas, such as the northern peninsula, prostrate creepers and grasses (Euphorbia, Sesuvium, Sporobolus) are most important. Ambrosia hispida also covers considerable areas. Round the exposed western margin of the sandy area, one finds, in addition to coconuts and tall grasses (Andropogon), Tournefortia gnaphalodes, Suriana maritima, Conocarpus erectus, and very infrequently Coccoloba uvifera. On the eastern shore, Coccoloba is much more widespread, though often stunted, and with Suriana and Conocarpus it is the dominant tree of the sand-cliff top. Rhizophora mangle, straying from the main mangrove areas, and Avicennia are found in places along the sand area margins, particularly close to the mangrove zones.

Because of lack of time, no detailed levelling could be done, except on the northern peninsula. As mentioned, this consists of a number of concentric ridges, the innermost vegetated with creepers and grasses, surrounding an internal area of vegetated fixed dunes. Much of the peninsula is cleared of all except ground vegetation, and the irregular steep hummocks of the dunes can be clearly seen. The line of section, through the middle of the peninsula from north to south, includes four dune ridges, rising respectively to elevations of 5, 5, $7\frac{1}{2}$ and $10\frac{1}{2}$ feet above sea-level. These are maximum elevations for the particular ridge; the fourth ridge is the highest on the peninsula, and it is unlikely that any higher point is found on the island. The outermost of the dune ridges has dammed up a small lenticular pool of stagnant water on its landward side. With the exception of Ambergris Cay on the Barrier Reef (not a true cay, in the strict sense, but a peninsula), this area of dune development at the northeast, windward side of the Northern Cay is unique on the British Honduras reefs, for dunes do not normally occur on these sand cays.

There are two or three small huts at the northeast side of the island, used by the cocal caretakers; one of these, near the pier, is in ruins, and this, combined with the unusual bare dune hummocks, gives a desolate, abandoned appearance at first sight. Well-water is available, but the men rely mainly on rain-water collected in drums and vats. The owner of the cay, Mrs. Ben Stuart of Belize, told us of historical remains in the form of large earthenware containers (?) about 4 feet tall on the cay, but unfortunately these were not seen during our visit. The possibilities for further work on this cay, both for physiographers and zoologists, are immense, and more than any other island on the three British Honduras atolls, Northern Cay would repay more detailed investigations than we had the time to make.

Saddle Cay

Saddle Cay is situated on the east reef of Lighthouse Reef, 2 3/4 miles north of Half Moon Cay, at the inner edge of the main reef-flat, here over 1500 yards wide. Its location is rather inexplicable, for there are no gaps in the east reef at this point, and no particular reason why a cay should form here. It may result from some irregularity in the rock floor dating from glacial times, and serving as a basis for debris accumulation. The present cay is now only a remnant of a former larger island,

and in fact is too small to be usefully shown on a map. It stands on a larger arcuate sand shoal, convex to the north, and as seen on air photographs over 200 yards long. The dry land area is roughly circular and has a diameter of 10 yards; it is sandy with some small shingle, and does not rise more than 2 feet above sea-level. There are two small areas of sandy beach, thickly covered with Sesuvium, and with mounds of dead Thalassia cast up at the limit of wave action. Sesuvium blankets the greater part of the cay area. To a very large extent the island consists simply of half a dozen mangrove trees, partly on dry land, partly in water. On the east and south sides these include Rhizophora mangle; and on drier land on the east side, tall gnarled Avicennia. The vegetation on the west side of the sand patch is lower and less dense—Avicennia and Conocarpus, with a ground mat of Sesuvium, and two tall coconuts. A third coconut only a few years old is growing near the shore.

The cay was formerly more extensive, and has been much eroded in recent years. Before 1931 it was some 50 yards long, but was reduced to half this length in the 1931 hurricane, and by half again in 1942. Other hurricanes have progressively destroyed the land area until only a clump of trees remains. A large hurricane passing over the cay now would probably destroy it altogether. It is still possible to trace the extent of the older cay in a submerged sand shoal. This extends for about 50 yards in a broad curve eastwards from the cay, and normally carries 6-12 inches of water. The bottom is very soft, covered with worm mounds, and one or two tree trunks are stranded on it. West of the cay there is a similar but much shorter submerged spit, a deeper scour hole, and one or two remnants of a submerged sand-flat beyond. On this western spit two large tree-trunks have been washed up, and ospreys had built a nest there and were breeding in 1960. The nest was nearly 3 feet across, built of sticks and some coral rubble.

One of the first accounts of the British Honduras cays concerns Saddle Cay, for it appears that Nathaniel Uring spent several days here after being shipwrecked in February 1720. He does not name the cay, and it is impossible to be certain, but Jefferys (1775) marks the wreck of Uring's ship, the Bangor, on Lighthouse Reef, and Saddle Cay is the nearest cay to this. Uring's account is here quoted; the cay on which he lived is thought to be Saddle Cay, and that visited for water Half Moon Cay. It is interesting to note that on Jefferys' map Saddle Cay is shown as an island comparable in size to Half Moon Cay.

Uring's account of Saddle Cay, 1720

> "When it grew light, we found ourselves upon a Shoal of Rocks about Two Miles from any dry Land, there being a small flat Island or Key at that Distance, and farther off we saw several more little low Islands. There was near a Foot Water upon the Reef where we were lost, the Surge of the Sea leaving it bare at time, some perched Rocks appearing above Water... the shoalest Part of it being about One Hundred and Fifty Yards broad, and then the Water deepen'd. ...

We got ashore some Goods and Provisions, and put them into the Long-Boat, and carried them to the nearest Island. ... In the Morning, we searched the Island for fresh Water: and by the Footing of Birds we discovered a small Pool under the Cover of a Tree, at which we were exceeding glad; but it being only Rain Water, we drank it out in a very few Days. ...

When we had been about Ten Days, and finding our Water grew scant, we went to the next Island, where we found Plenty, with which we fill'd our Cask; and we likewise found there several Cocoa Nut Trees full of Fruit; we gathered some of the Nuts, and returned to our Island again, where I planted several. We found one Tree growing on it when we landed, but too young to bear Fruit."

Tiring of his "desart Island", Uring decided to make a raft; "there being a great many dry Trees on the Island, we went heartily to work to cut them down; but being Mangroves which is hard and heavy, I suspected they were not fit for our Purpose, and therefore put one of them into the Water to see if it would float, and found it would hardly swim." He then used wreckage from the Bangor, completed the raft, and departed, "leaving on the Island five laying Hens and a Cock to breed, we set forward on the Afternoon, and by Night reached the next Island, where we remained all Night, and in the Morning set forward again, but found a good deal of Difficulty in passing between that Island and a Reef of Rocks, till we came onto the open Sea... (and) made Tournef." (Uring, 1726; from the 1928 edition, pages 234-240). Uring reached Belize safely, and in his book includes many useful tips on raft-building for mariners in similar distressing situations.

Half Moon Cay

Half Moon Cay (fig. 30) is the largest simple sand cay on Lighthouse Reef and one of the largest on the British Honduras coast. It is located on the almost unbroken eastern reef of Lighouthouse Reef, at the point where the reef turns sharply westwards in a prominent elbow, sweeping southwestwards to form the half-moon-shaped Southeast Bight. To the north of the cay the east reef extends uninterruptedly, with a smoothly scalloped plan, for 18 miles; immediately westwards, the east reef is broken by two gaps each a thousand yards wide. The cay lies with its long axis parallel to the reef forming the northern edge of the southeast bight, and hence transverse to the main eastern reef-flat, here some 2,000 yards wide. Immediately southeast of the cay, the bank is prolonged by a submarine spur, visible on air photographs (CAE-6-176), carrying 7 fathoms of water, but the vigorously growing reef on this spur does not reach the surface as a continuous reef.

It has been visited by the ornithologists Salvin and Verner on account of its pink-footed booby colony, and Verner in particular (1959, 3-8) has given a fairly full and valuable description of it, with particular reference to vegetation. He also produced a sketch-map of the cay on a scale of 1:6000, showing the location of broadleaf forest and the booby colony. Vermeer also visited the cay in 1957, and gives a

brief general description (1959, 97-103). Ten days were spent on this cay in April 1960, and a similar period in May-June 1961. The cay was mapped in detail, 32 lines of levels were surveyed across it, and subsequently used for a contour map, plants were collected on both occasions, mainly from the area outside the high broad-leaf forest, and 130 sediment samples were taken for later analysis. Reef transects made near the cay have already been described (transect C, Section IV). Much of this material, especially the sediments, has yet to be studied, and this account is thus a general one, similar in purpose to the other cay descriptions in this paper. It is hoped to produce a more detailed report on Half Moon Cay at a later date. The cay was photographed from the air in July 1961.

While the island may be thought of as forming a crescent or half-moon shape concave towards the lagoon, it may be described more easily in terms of two units. The southwest segment of the cay consists of a quadrilateral 700 yards long, with a uniform width of 200 yards. The south, west and north shores of this quadrilateral are linear in plan. Extending northeastwards from this part of the cay is a tapering peninsula 650 yards long and over 250 yards wide where it adjoins the first segment. This peninsula trends northeastwards for all but the last 200 yards of its length, where it curves towards the east, and comes to an end in a series of steep shingle ridges overlooking the eastern reef. While these two segments are distinguished primarily for ease in description and imply no physiographic or structural distinction, they are clearly evident to the student of vegetation: the first, rectangular segment is covered with dense low broadleaf forest and coconut thicket, while the second peninsular segment has been completely cleared for coconut plantations.

Beaches

The cay is highest along its south and southeast shores, fronting the ocean, and both of these shores overlook expanses of beachrock and conglomerate (fig. 31). Of these shores, that facing southeast (forming the south shore of the peninsula) is most exposed to the prevailing easterlies; while the shore facing slightly west of south (forming the south shore of the main body of the cay) is accessible only to the southeasterlies and to waves refracting round the east reef elbow. The least exposed southern shore is hence lower than the southeastern. At the same time, since it overlooks fairly shallow water immediately offshore, with a profuse growth of rough water corals (Acropora palmata, A. cervicornis, Millepora), on which short period waves continually break, the lower shore is built of coarser material than the higher southeastern shore. The effects of exposure are also clearly visible in the changing nature of the shingle ridge along the shore itself, for wave action is strongest at its eastern end, and decreases westwards. Most observed waves on this southern shore approached from the southeast at an angle of 45° to it, and had lost much of their force by the time they reached the western end. Thus, while the whole south shore is built of shingle, it rises to a height of 7 feet near the eastern end and declines eastwards to heights of 4 feet and less. At least three "populations" of sediments constitute the ridge: an upper zone of blackened, pitted coral blocks, 6-15 inches in diameter; an intermediate

zone of white, relatively unweathered, finer coral debris, 1-6 inches in longest diameter; and a lower zone with many larger blocks, often 1-2 feet across, of yellow broken coral, lying at and above sea-level. These zones are distinguished, not only by size differences, but by colour, for the yellow, white and black zones occur constantly. A fourth "population" consists of small pockets of coarse sand at the foot of the shingle ridge, the largest being located near the middle of the south shore. The corals of the white zone are all relatively fresh and unbroken and include A. cervicornis, A. palmata, Montastrea annularis, M. cavernosa, Diploria strigosa, D. labyrinthiformis, D. clivosa, Siderastrea radians, S. siderea, Porites porites and Meandrina meandrites, with still-segmented Halimeda and many Strombus shells. These figures and composition data refer to the eastern section of the ridge; westwards, the proportion of coarser material lessens, and the species-composition of the ridge changes, presumably reflecting changes in the offshore reef. A. palmata, for example, becomes less important, and the smaller corals (Siderastrea, Porites, Favia) more so. The upper part of the ridge throughout its length is covered by a low, spray-swept "hedge" of broadleaf trees. Inward from the vegetation margin the ridge rises to a crest, and slopes gently backwards; the uppermost section of the ridge, and the backslope, consists mainly of coarse grey sand and scattered large blocks.

Sediment composition of the more exposed southeast shore varies from coarse sand through small coral shingle to coarse shingle and large blocks several feet across. The floor of the southeast bay shelves steeply to depths of more than a fathom, and a few hundred yards from shore reaches constant depths of 7 fathoms on the southeast submarine spur. Coral growth in the bay is patchy, though locally profuse. Most of the bay is sand-floored, and the water nearshore is so turbid with suspended sand that visibility is nil; the nearshore reef patches, which are concentrated near the western end of the bay, consist mainly of Acropora cervicornis, massive A. palmata and Porites astreoides; while seawards in deeper water the reef consists of very large tree-like A. palmata. The absence of a continuous fringe of reef, in contrast to the south shore, probably results from the amount of sand in suspension. Sediment distribution on the beach is largely controlled by the distribution of beachrock at its base; generally, where beachrock is well-exposed, the beach consists of sand and small shingle; where it is not developed, the waves have access to the beach itself and have thrown up ridges of larger shingle. In places the beachrock itself has been torn up and thrown up the beach in large blocks. The distribution of these types of sediment is shown on the map. The sediment composition reflects that of the reefs: the finer shingle is overwhelmingly short, cylindrical sticks of A. cervicornis, the larger shingle slabby plates of A. palmata. In places Strombus shells form 30-40% of the larger-shingle ridge. Taken as a whole, however, the beach is sandy, especially at the southeast corner of the cay, where a double sand ridge rises to a maximum height of 9 feet above sea-level. According to Vermeer, "the cay rises to a height of from 15 to 18 feet along the seaward face" (1959, 97), but this is only an estimate. The southeast ridge-crest is almost everywhere more than 7 feet above the sea, and towards its southwest and northeast ends everywhere above 8 feet. From this general crestline

isolated mounds rise higher, and can clearly be seen in profile from the backslope of the ridge. Two areas rise above 9 feet (a third is located at the extreme southern point), and the highest part of the island, 10.5 feet above the sea, is found on one of these, approximately 120 yards west of the lighthouse.

At the eastern end of the island, exposed to the easterlies and fronting the eastern reef, three concentric shingle ridges (yellow, white and grey-black zones) rise to a height of 6 feet above the sea. This shingle complex extends for 80 yards from the east point along the southern shore of the peninsula, and for 250 yards along its north shore, reflecting the unequal exposure of north and south sides. The full suite of three ridges is found only near the east point itself: along most of the north shore, the ridge is a single feature gradually being pushed back across a lower sand shore; it has a height of $2\frac{1}{2}$-3 feet only. The size of the shingle at the east point is broadly comparable with that on the south shore, and may have similar origins. It is thought that the white zone consists of small material continually thrown up by day-to-day wave activity and storm action; the larger blocks of the yellow zone consist of dead corals torn loose by larger waves which can roll them across the reef-flat but lack the power to throw them up the beach; while the large eroded fragments of the black zone are cast up beyond the reach of day-to-day waves by exceptional storms and hurricanes, and subsequently are exposed to weathering and degradation.

With the exception of the low shingle ridge along its extreme eastern end, the northern side of the cay is formed by a wide, gentle sand beach, overlooking a bay with 1-2 fathoms water. This bay continues northwards as the main eastern reef-flat, across which strong currents flow transversely. Except in time of northers, when material is thrown up along the beach, the bay is calm and sheltered. Most of its floor is covered with thick *Thalassia*, with abundant scattered colonies of large *Manicina areolata*, and very occasional *Porites furcata* and *Siderastrea radians*. Holothurians are numerous toward the east side, near the main reef. The most abundant reef in the bay, paradoxically, is at its west side, where waves refract round from the south side of the island. Here small reef-patches are developed, consisting of *Porites astreoides*, *Montastrea annularis*, *M. cavernosa* and *Siderastrea siderea*. The water in the bay itself, where circulation is restricted, becomes much overheated, and in places near the shore is scum-covered and rather stagnant, with luxuriant bottom growths of green algae. The beach round the bay is everywhere low and sandy, and no beachrock is exposed. The northwest-facing shore of the bay (most protected) appears to be prograding; but the northeast-facing shore, though also low, is suffering wave erosion, for it is fringed by fallen and dangerously leaning coconut trees, the beach is narrow, and a cliff has been formed about a foot high.

Finally, the western shore, exposed only to refracted waves produced by the southeasterlies. It is highest at its south end (2-3 feet), where it is formed by the tapering end of the south shore ridge, and declines northwards. The shore forms a slight bay, containing a broad beach of fresh, unconsolidated sand, on which vegetation is just beginning to encroach.

Cay surface

In view of the height of the seaward ridges, the greater part of Half Moon Cay lies at a surprisingly low level; the narrowness of the belt rising above 6 feet is apparent from the map--it generally forms less than one quarter the width of the cay. It is perhaps misleading to term the slope of the cay surface "gradual", as Vermeer does, as this may imply straightness. The backslope of the ridges is in fact concave: large areas on the leeward side lie below 3 feet, and the surface rises steeply from this lower level to the ridge crest within an average distance of 30 yards. The contouring of the cay surface, while liable to error in the vegetated areas, shows a pattern of alternating lobes, extending back from the ridges, and intervening depressions; though it is probably too simplified a view to regard the lobes simply as growth stages in the lateral extension of the cay, as in the evolution of sand spits. The intervening depressions often form closed basins, cut off from the northern bay by the low sand mound along its shore. One of these depressions, locally known as "mudhole", permanently holds wet soil and water; another (near the middle of the main segment of the cay) contains water only after heavy rain. Verner (1959, 4) maps both as mudholes, but at the time of our visits the western one was dry. On the other hand, small areas of standing water have been seen in other parts of the leeward side of the cay, but persist for only a short time after rain. The main mudhole is now some 10 yards long and 6 yards wide, and it seems that an effort has been made to fill it in in recent years with coconut trash and husks. The "soil" in the hole is an extremely black organic material (in American usage, a "muck"), which augering in several places showed to be only 6 inches in thickness, underlain by rather evil-smelling, white, unaltered coarse sand.

The cay surface, apart from the sediment variations on the beaches, consists only of coarse coral-algal sand, with greater or less admixture of fine coral debris (see Section VIII for notes on quantitatively unimportant non-limestone constituents). A distinction may be made between the eastern cleared area and the western wooded one. The east end is under coconuts with no ground cover; the soil is a scarcely altered coral sand with added humus, forming a brown layer 25-30 inches thick, gradually grading into coral sand with no added humus. The soil loses much of its colour on drying, and seems comparable to the Shioya Series of the Pacific (Stone 1951, Fosberg 1954). The soils of the western end have a higher humus content and contain more large coral debris. In places this is sufficient to form an actual ridge. The pattern of surface shingle on this part of the cay cannot be traced until the higher vegetation is removed, but it must either relate to an earlier period in the cay's development and mark a former shoreline, or be a form of "rampart wash". Its distribution is shown as far as possible on the map; it lies at 3-5 feet above the sea.

Specimens of the more humic soil were taken on the north and south sides of the vegetated area and await analysis. Near the geographical centre of the cay occurs yet a third main soil type. Here, under a small area of high thicket, the soil is a rich brown humus, in places only a few centimetres thick. Wherever excavated, it reveals an irregular surface of yellow, speckled, seemingly rather decayed rock of

uncertain origin. This layer seems continuous and solid; it is impossible to delimit it because of the very dense vegetation, but it probably covers an area of at least 100 yards in length and 50 yards in width. The matrix of the rock includes a number of recognisable corals similar to those scattered over the adjacent cay surface, mainly Montastrea annularis, M. cavernosa and a Diploria. The cay surface here lies at approximately 4 feet above the sea. The hardpan is either the upper surface of a block of upraised reefrock, in which case it would have important implications for the history of the cay, or it is a subsequent alteration product of the cay surface itself. In this connection it bears at least a superficial resemblance to Fosberg's Jemo Series (Fosberg 1954, 101-106), where the induration results from phosphatic cementation, associated with surface guano staining. The western woodlands on Half Moon provide a nesting ground for many thousands of birds, and the ground is stained over large areas with guano. However, in areas where guano staining is heaviest, no cementation is found. Verner comments (1959, 8): "The Hermit Crabs and Soldier Crabs figure prominently in the booby colony... They eat everthing... as well as the excrement of the birds. This latter activity combined with the porous substrate and high annual rainfall on Half Moon Cay, accounts for the absence of guano accumulation in the booby colony." Analyses of this rock are awaited with interest.

In the cleared eastern part of the island, wind erosion of the sand surface seems important. Many of the boles of the coconuts are exposed on the surface, and stand above its general level, and in many places a mat of fine coconut roots can be seen. A moderate ground cover would probably halt this, though it would undeniably detract from the great beauty of the cay itself.

Coast beachrock and conglomerates

The areas of beachrock and conglomerate on the seaward side of the cay are shown in detail on the map. They were noted by Vermeer (1959, 99-100), who distinguished

(a) "a coral platform (which) extends for as much as 100 yards (to windward of the cay). On the platform, pieces of reef rock are exposed at low tide, and in some cases broken pieces of reef rock thrown up on the platform and in other cases an exposed part of the platform itself. None of these pieces is more than six or eight inches above the water level"; and

(b) "five separate areas of a greyish sandstone or beach rock ... (which) consists of separate slabs of poorly cemented but clearly stratified beds of sandstone. Individual slabs of beach rock are generally from 4 to 6 feet long and about a foot thick and compare in hardness to a poorly cemented sandstone."

These are illustrated in Vermeer's Figures 24 and 22, 23 and 26 respectively. In this section the exposures will be described, and the difficulty of drawing very clear distinctions will be apparent. Seymour Sewell, among others, has stressed the importance of clearly differentiating between several types of lithified material on reef islands; and it is one of the more vexing problems of Half Moon Cay that (with the exception of the more extreme members of the spectrum of rock types) it is difficult, if not impossible, to do this.

The most extensive area of rock is at the southernmost point of the cay, where it extends in a continuous exposure for over 200 yards, and projects for 75 yards seaward of the cay shore itself. It here forms a platform, with a maximum width of 30 yards, its upper surface slightly above low tide level, on which waves break heavily. It is separated northwards by channels at least 5 feet deep from similar areas of rock, lying at the same level, again pounded by waves. This is the exposure described by Vermeer as the "coral platform" and shown in his Figure 24. The upper surface of the rock is deeply pitted and eroded into sharp ridges and depressions; it is coloured yellow-green and is slippery underfoot. Its outer edges, in the zone of wave action, support a profuse growth of orange, brown and green algae. Vermeer mentions the "pieces of reef rock... six or eight inches above the water level", but in some cases these are considerably higher. One such patch is found on an isolated platform north of the main exposure. Levelling showed that the upper surface of this remnant was 1.8 feet above low water level, and in detailed structure it consists of a slab of blackened, well-cemented calcarenite, dipping seawards, overlying a slightly undercut layer of finer calcarenite rising from the general level. The interface between the upper block and its basement dips seawards some 2 inches in $2\frac{1}{2}$ feet. A second example is found rising from the main platform itself on the southwest side of the cay close inshore. This too rises 1.8 feet above low tide level, and consists of a seaward-dipping block of hard rock overlying a slightly undercut base rising from the general level; again the seaward dip is about 2 inches in $2\frac{1}{2}$ feet. These remnants both consist of very well indurated sands, similar to beach sands, in which some alteration of constituent grains has taken place. The rocks of both the relict beds and the platform is distinguished by its strength; it rings to the hammer, and very heavy blows are necessary to secure specimens. Several other pinnacles approach close to the level of the tabular outcrops, but do not show seaward dip. The platform itself, however, is not entirely horizontal, for where it projects from the cay three distinct low escarpments, 2-4 inches high, can be seen parallel to the present outcrop, with apparent dip to seaward, in the same direction as that of the second tabular remnant described.

Is this then an exposed reef conglomerate, or a beachrock, now degraded, properly so called? The dipping structures might suggest the latter, though there is a remote possibility (especially for the small scarps of the platform itself) that they result from jointing and tilting. The high tabular relicts are almost certainly a beachrock—they consist of beach sands and dip seawards (on the southwest shore to the southwest, on the southeast shore to the southeast). The widespread evidence of erosion shows that formerly the whole surface must have stood at a level close to that now represented by the beachrock remnants: was this surface wholly formed of thick beachrock, or did it overlie reefrock at no great depth? The surface of the lower platform bears a very great resemblance to raised reefrock surfaces seen by the writer on the north coast of Jamaica, but the example stresses the importance of precision and care in applying labels to lithified outcrops on cays. The rock itself consists of much-recrystallised detrital material, with Homotrema, similar to that now found on the beaches, together with

larger fragments, mainly broken Strombus shells (usually worn) and corals. Many of the smaller pinnacles are formed by out-weathered coral heads and are still identifiable, though it is impossible to say whether they are in the position of growth. The inclusion of corals, often relatively numerous, in the rock does not necessarily have much bearing on its origin, for equal amounts of coral material are found in rock which is demonstrably beachrock, elsewhere on this cay.

Much of the southwest shore is fringed by a narrow outcrop of similar rock to that at the south point, forming a low ridge 1-2 feet wide, rising slightly above low tide level (though continually wetted by breaking waves), and often separated from the shore by a narrow shallow moat. The presence of this moat in places gives the rock an apparent surface dip to landward, where it is obscured by the shingle ridge; but excavation in the ridge shows that the rock reappears there for at least a small extent, at a slightly higher level than to seaward, and hence the true dip (if such exists) is from land to sea, the moat being erosional. The crest of the exposed ridge carries a very luxuriant growth of brown and green algae, which give it a distinctive appearance; on the seaward side it is undergoing severe erosion by grooving and potholing. It is impossible to speculate on the origin of this exposure, except to say that it is probably linked to that at the south point, and is not now in the process of formation.

The southeast bay contains a number of outcrops of lithified material, mostly intertidal, though descending at their outer edge below low tide level, and in one or two cases rising landward above high tide level, but still within the reach of swash and spray. These include Vermeer's "five separate areas of a greyish sandstone or beach rock", comparing in hardness to a poorly cemented sandstone, and "composed not only of cemented sand but contain(ing) shells, pieces of coral and coral rock" (Vermeer 1959, 99). Much of the rock is very much harder than Vermeer suggests; this is particularly so of the cemented beach conglomerates, but even finer beach calcarenites are consistently so well lithified that repeated heavy blows are needed to secure specimens. The best general view of the rock is obtained from the top of the lighthouse at the east end of the island. There are two main outcrops: the first, along the north shore of the bay, is mainly a calcarenite; the second, along the west side of the bay, also includes calcarenites, but with a large proportion of conglomerates. Generally, the proportion of purely sandy beachrock is greater in the middle of the bay than towards its extremities. The coarsest material is found close to the south point, where it has been much disrupted by wave action, and now lies in a jumble of slabs up to 10 feet long, some obviously inverted, piled on the steep beach ridge. Immediately seaward and to the north, enough of this rock remains in its original seaward-dipping intertidal location to identify it as a true beachrock. Strombus shells are very prominent in the rock, as in the beach deposits of this bay, together with identifiable corals (mostly Montastrea and Diploria), and sticks and plates of Acropora). The slabs have a maximum thickness of about 18 inches, they are extremely tough, and compare in hardness to the south point rocks.

Northward the proportion of coarse material decreases, and several distinct layers of rock (up to 5) outcrop on the beach, dipping seawards, forming miniature escarpments up to 9 inches in height. They often show a distinct variation in content, layers of fine calcarenite alternating with layers of conglomerate, containing few recognisable corals but much cobble material. Some sorting is also to be seen within the individual calcarenite layers, between fine sands with Homotrema, and coarser sands with much Halimeda. A layer of pure Halimeda sand about half an inch thick often tops the calcarenite layer, much as on uncemented modern beaches. In general the coarser sands tend to be less well lithified than the finer. The beachrock in this bay reaches a maximum thickness of 10 yards.

The exposures along the north side of the bay are narrower, but similar in composition. The rocks are more sandy,with scattered patches of coarser fragments within the sand layers. Distinct conglomerate layers are found occasionally. The beachrock round the whole bay is being eroded by the formation of miniature groove-spur systems on its seaward side, and these often develop into potholes containing large cobbles. The outer lower parts of the beach rock are covered with a rich growth of green and brown algae, distinctly zoned (the identifications are awaited); the inner zones are free from larger algal colonists, but are coloured blue-black or yellow, presumably by encrusting microscopic algae. At several places along the shores of the bay, iron bars can be seen incorporated in the rock, and are now much rusted and decayed; at least 5 examples were seen. Hence the induration dates from later than about 1700, when this coast first began to be colonised and visited, and quite probably since 1830, when the first lighthouse came into operation. Apart from these bars, no inorganic material, such as pumice, was seen in the beachrock.

But perhaps the most interesting fact about the southeast bay beachrock is that thirty years ago none of it was to be seen. Prior to the 1931 hurricane, the seaward beach of this part of the cay stood 20-30 yards further seaward than it does now, and was sandy throughout. The hurricane destroyed this sand beach, and in effect bodily pushed the cay back that distance, exposing the present beachrock virtually overnight. The amount of this exposure seems to have been greatest in the centre of the bay and least towards its ends: northeastwards the beachrock still passes under the cay sands, but in the middle of the cay the rock has been subsequently obscured by a covering of fine soft, constantly shifting sand. The pre-1931 sandy shore seems to have been in existence for many years. Jefferys in all his maps (1775 and later) marks a prominent "Sandy Bay" on this side of the island, with, it is significant to note, a conspicuous southern lobe along the line of the present rock platform at the south point. Owen's 1830 MS chart, too, shows a similar configuration. It is at least possible, therefore, that all the rock now exposed developed during a previous more seaward extension of the cay, and has been relatively recently exposed. One would give much for detailed maps of this cay in 1930 and earlier!

No beachrock is found on the northern shores of the cay.

Evolution of the cay

It is thus impossible to understand the present physiography of the cay without reference to the 1931 hurricane. At certain places along the south shore, blocks of beachrock and conglomerate are found perched on the beach ridge 809 feet above the sea, and some are even found a short distance down its backslope. Residents describe seeing these blocks being rolled up the steep seaward beach at the height of the storm in 1931. The orientation and depth of the southeast bay gives large waves access to the beach itself, and these normally break heavily in great clouds of spray on the beachrock, or where this is absent, on the beach itself, the swash wetting the sand for some distance above high water level. In times of violent storm and hurricane, the swash is so great that it overtops the ridge crest (7-9 feet high), depositing fresh sand there and on the upper part of the backslope. This occurred recently during the comparatively minor hurricanes Abby in 1960 and Anna in 1961. Sediment also accumulates in the northern bay by refraction chiefly round the east point, but whether the aggradation has yet made up the 1931 net losses is not known. The continuing progradation of the lagoon shore may account for the apparent or real absence of beachrock on this shore.

Verner makes the point that the present brick lighthouse base was built in 1845 "midway between the north and south sides". If this is so, then as he says "hurricanes have actually moved Half Moon Cay northward while not affecting the position of the Lighthouse" (1959, 9, 12). The base of the lighthouse now rests immediately overlooking the seaward slope of the ridge, and any further retreat will lead to its undermining, though this is unlikely without the intervention of another major hurricane.

Vegetation

Our knowledge of the present vegetation on Half Moon Cay is fairly full, while of its development, though data are meagre in the extreme, we at least know more than for any other cay. In the account of Saddle Cay it was shown the coconuts were already established on Lighthouse Reef in 1720, and it seems that Uring found a number on Half Moon Cay in that year (Uring 1726; 1928 edition, 236). Alone of the British Honduras cays we have an early sketch of Half Moon, made in 1828 or 1830 from the south. This is redrawn and given here (fig. 32); it shows the absence of all except low bushes and shrubs at the eastern end of the cay, while fully two-thirds is occupied by high forest. Only half a dozen or so coconuts are indicated in this sketch at the margin of the high bush and cleared area. (I am indebted to Chart Branch IX, Hydrographic Department, Admiralty, for allowing me to search their volumes of views and finding this sketch for me; it is in Volume 1, No. 362). The sketch was made in 1828-9, shortly after the building of the first lighthouse; the Honduras Almanack for 1830, reporting this event, describes (on p. 150), a "luxuriant growth of the wild plum and salt-water palmetto, over which the cocoa-nut tree may be seen towering in majestic grandeur."

Mr. George Young, resident on the cay since 1928, informs me that when he first came, the high bush extended to a point half way along the northeastern peninsula, and thus it cannot have been much less extensive in 1928 than in 1830. During the four decades since 1928, Mr. Young and his family have slowly cleared the high bush from the whole of the peninsula (fig. 33), and it is now restricted to the western portion of the cay, especially along its southern side. Nearly all the peninsula is now planted to coconuts and is devoid of ground vegetation; while the high bush area is surrounded by a fringe, particularly on its northern side, of low ground vegetation and bushes, intermixed with coconuts. It is interesting to note that as the lagoon beach builds outwards, Mr. Young is planting additional rows of young coconuts in line with the old, so that as one approaches the lagoon shore from the crest of the seaward ridge, the coconuts become lower and younger. It cannot be too strongly emphasised that the existing pattern of vegetation on inhabited cays like Half Moon is ephemeral, and indeed the vegetation of some cays visited in 1961 was almost unrecognisable as that seen fourteen months earlier (e.g. Tobacco Cay, Barrier Reef), simply because of the activities of man. The vegetation is periodically cut back, and sometimes rooted out altogether. Mr. Young's programme of systematic clearing is at present being continued by Mr. Philip Young, who is cutting out the *Cordia* bush at the southern point, and the mixed *Cordia*-*Conocarpus* bush behind, for *cocals*. The vegetation of this middle part of the cay was in 1961 covered only with low bushes and ground vegetation, whereas in 1960 when first seen, it was a confused tangle of tall *Conocarpus* and other bushes. A small amount of vegetation still covers the shingle ridges at the east end of the island.

Verner gives a description of the composition of the broadleaf area, as follows (1959, 3-8):

> "The principal tree, both in numbers and in utilisation by the boobies, is the red-flowered *Cordia sebestena*. It is the only tree that occurs in all sections of the (booby) colony, and the only one growing next to the shore. Most individuals are about twenty to twenty-five feet high, but some attain thirty-five feet. *Bursera simaruba* occurs generally in all areas of the colony except along the shore, and *Bumelia retusa* occurs in all areas except along the the shore and in approximately the eastern fifth of the colony. *Ficus* sp. is distributed like *Bursera* but is much less common. *Pithecellobium keyense* grows only in the central portion of the colony. ... *Neea choriophylla* is a very rare species in the colony... I was aware of not over five individuals of the species on the island, and all but one of these were in the eastern fifth of the booby colony. *Ximenia americana* is also rather uncommon, and is restricted to the northwest corner of the colony. *Pouteria campechiana* is one of the principal species along the north border of the eastern half of the colony, where it occurs in association mainly with *Bursera* and *Ficus*. Those three species reach heights of forty to fifty feet in that section of the colony,

and they are the principal species composing the remainder of the broadleaf grove where the boobies do not rest."

He also noted the abundance of the night-flowering bush Capparis flexuosa, forming "dense tangles of stems throughout most of the central section of the nesting colony."

I can add little to this account. The whole of the south shore of the cay is lined with Cordia sebestena, forming a low, spray-swept hedge, most noticeable (till cleared in 1961) at the south point. Verner (1959, 57) thinks this shearing is due to birds collecting nest materials, and he quotes Mr. George Young as saying "he had seen a number of boobies practically strip a small bush to the trunk before leaving it to gather sticks elsewhere." He considers frigate birds and ospreys, as well as boobies, to be the culprits. I consider that the shearing results from salt spray and wind-trimming (Boyce, 1954), rather than from the birds. Verner states that "neighbouring cays exhibited no such trimming of shoreward vegetation", but this is true only of the cays lacking broadleaf forest (the majority). Wherever one still finds cays with broadleaf forest on the windward side, then one finds shearing even in the absence of birds. Examples are seen on Northeast Cay and other cays on Glover's Reef, and several of the Sapodilla Cays, Barrier Reef.

Most attention in my visits was given to the lower vegetation cover surrounding the broadleaf forest, and 30 plants were collected here and sent to Dr. Fosberg for identification. A map (fig. 34) has been constructed showing the distribution of the main species in this area. Tournefortia gnaphalodes occurs around the cay margins on both shingle and sand, particularly in exposed places. It is dominant on the extreme eastern shingle ridges (with stunted Cordia, some coconuts, Hymenocallis and Sesuvium), and also occurs on high ground at the south point, near the northwest corner of the cay, and intermittently along the southwest shore below the Cordia hedge. Sporobolus virginicus is a sand-binding grass found in similar exposed locations on sand beaches: again it is important near the south point, along the south shore, at the northwest corner, and along the beach ridge of the lagoon shore. Suriana maritima is another shrub of exposed shores, rather oddly restricted here to the northwest point. Other colonising strand plants such as Sesuvium and Ipomoea are not well developed on the Half Moon beaches, except at the west end of the island.

The area surrounding the high bush falls into three vegetational zones: the eastern zone, the central zone, and the western zone. Wedelia trilobata, with Cakile lanceolata and Ipomoea, forms the ground cover in the west zone, behind a fringe of Tournefortia and Suriana; and Verner records Calonyction aculeatum from this area also. The central zone, round the western mudhole, is composed mainly of Wedelia, scattered Stachytarpheta jamaicensis, low bushes such as Rivina humilis, and, shorewards, a broad belt of the lily, Hymenocallis littoralis. The eastern zone extends along the east side of the high bush zone from the south shore to the north. In the south, on the crest and backslope of the windward ridge, there is a narrow zone of Tournefortia, succeeded inland by a broad belt with little but Hymenocallis. The middle of the cay in this zone, south and west of the main mudhole, is covered with

extensive patches of Wedelia trilobata, Cyperus planifolius, Alternanthera ramosissima, Eragrostis ciliaris, Ageratum maritimum (recorded by Verner), Sida acuta (Verner), and bushes such as Rivina humilis, Ernodea litoralis, Hamelia patens, Erithalis fruticosa, and Conocarpus erectus. According to Verner, Sida and Hamelia "are confined to the moist, shady areas bordering the broadleaf tree stands". The mudhole itself stands in the middle of an almost exclusive mat of Wedelia trilobata, while to the north, between the Wedelia stand and the Sporobolus-covered lagoon beach-ridge, is an area of mixed Wedelia, Euphorbia, Cyperus and Sporobolus.

Almost one-third the area of the cay is still covered with high bush, but it is clear that the period of extensive clearing from 1928 onwards is coming to a close. First, much of what is left is a protected booby colony and cannot be cleared, and much of the remainder is underlain at very small depths by hardpan or reefrock and cannot support coconuts. Were the vegetation cleared here, the surface humus would soon disappear and a barren pavement would be exposed. The main change to be expected is the complete ground-clearing of the coconut undergrowth on the fringes of the high bush, involving the partial disappearance of species such as Wedelia, Stachytarpheta, Euphorbia and the grasses.

Occupance and land use

The giant lizards (Iguana and Ctenosaura) and the smaller anolids and the rats on this cay have already been mentioned, as have Verner's ornithological records. In his study of the colony of boobies (Sula sula sula) in 1958, he counted 1389 nests (more than a half in Cordia sebestena, about 85% in Cordia, Bursera and Bumelia combined), averaging rather more than two nests to the tree, containing about 3500 pink-footed boobies, of whom 500 were immature birds. Two percent of the boobies were brown, but each of these was mated with a white (1959, 15, 53). Much information on the habits of these boobies is given in Verner's thesis, which should be consulted by those interested.

The Young family has a thriving settlement near the middle of the north shore, where they carry on boat building. George Young builds boats from imported timber of up to 15 tons wholly by eye, without the aid of drawings or models, which is unusual even among British Honduran fishermen. Several houses are associated with the lighthouse at the east end of the cay, together with a number of sheds and rainwater vats. The lighthouse keepers do not long remain at any station, but in 1961 one of them was also building a fishing boat on the cay. The lighthouse houses are sturdy, hurricane-proof shelters, large and comfortable. The first lighthouse was built in 1820, and a light first shown on December 1st that year (Honduras Almanack, 1830, 76); it was replaced by another in 1845. The present brick foundation dates from this time. The present steel-frame tower was built on the old base in 1930, and was still unfinished at the time of the 1931 hurricane. Apart from the lighthouse, the main occupation of the dozen or so individuals on the cay is tending the cocals, taking the nuts to Belize, and fishing--for barracuda, grouper, snapper, jacks and others--and turtling. Turtles are taken in nets baited with small brightly painted wooden decoys, and are sold in Belize. A number of the coconuts are used on the cay

for coconut oil and water, which is fed to the pigs. In addition to pigs, the fishermen keep chickens and dogs. The island is occasionally visited by the Harbourmaster and a Customs launch, but is otherwise rarely visited. It is said that an attempt was made a few years ago by an American syndicate to purchase the cay for development as a holiday resort, but permission was refused.

Little is known of the history of the cay, though the Honduras Almanack referred to (1830, 151) tells the story of a violent, bloody-visaged spectre haunting the island at night, presumably the ghost of some unfortunate pirate. The apparition has now ceased to appear, and has been forgotten.

Conclusion

Half Moon Cay has been described at greater length than any other cay, partly on account of the length of time spent there and mass of data collected (much of it still unsifted), partly because of the great natural beauty of the island, partly because of the problems which it raises. Several conclusions emerge from the study, including (1) the importance of major hurricanes, even on so large a cay as this, in the evolution of the present physiography; (2) the great practical difficulty of distinguishing in the field between various types of lithified material and hence the difficulties of drawing conclusions from them; and (3) the constantly changing nature of cay vegetation, even over so short a period as 30 years. When as much information is available on other cays as there is now on Half Moon, there is little doubt that features which now seem simple and easy to explain will be revealed as more complex and enigmatic; for even such small and apparently insignificant features as sand cays are beset with difficulties and problems, few of which can yet be solved.

Long Cay

The great German geographer Carl Sapper visited Long Cay in the 1890s but published no account of his observations, and no further attention seems to have been paid to it until 1958, when Vermeer called there and later published a short description. The island (fig. 35) is located near the southern end of Lighthouse Reef, on its long, narrow "half-moon" extension, $2\frac{1}{2}$ miles west of Half Moon Cay, and some $3\frac{1}{2}$ miles from the southern end of the reef. The situation of the cay is somewhat peculiar: it does not stand on the windward reef-flat, here about 700 yards wide, sandy and strongly rippled with flourishing reef on its outer edge; nor does it lie on the leeward reef-flat, which strictly speaking does not here exist. Living reef is in fact absent on the whole of the western, leeward side of the cay, and the gap continues some distance north of it, forming the main entrance to the atoll lagoon. The cay occupies an intermediate position, almost in the centre of the "lagoon", here at its narrowest and shoalest; the water round the cay averages $1-1\frac{1}{2}$ fathoms in depth. The deeper channel between the windward reef-flat and the east side of the cay may be due to subsequent current scour of the bottom, as water surges across the reef, piles up against the cay obstruction, and is diverted southwards.

Long Cay is a narrow island, with its long axis parallel to the trend of the reefs and lagoon at this point. Its maximum length is approximately 3640 yards, and its width varies from a minimum of less than 300 yards in the south to a maximum of 1200 yards in the north. Vermeer's description of the cay is here quoted, since he found here features which he ascribed to a recent eustatic fall of sea-level:

> "A sand cay with a swampy, depressed centre, this cay has been almost completely planted to coconut palms. Long Cay appears similar to Ambergris Cay on the coastal shelf block in that it also gives indication of greater age and stability than the other cays" (1959, 97).

After finding a "raised beach" on Ambergris Cay, Vermeer described another from Long Cay:

> "....the elevated beach was manifest not only on the windward side but on the leeward side as well. Long Cay has an enclosed elongated lagoon toward the centre of the island. From this lagoon there is a rise to the ridge which surrounds the lagoon and which is the highest part of the cay. From this high part of the cay, there is a drop to the elevated beach terrace. The maximum width of the raised beach on Long Cay is similar to that on Ambergris Cay, being no more than about 20 yards, but displays less variation in width. From this elevated beach-level there is a drop of 5-6 feet to sea level. The elevated beach on the leeward side of Long Cay is much more clearly defined and illustrated than it is on the windward side of the cay and than is the case on Ambergris Cay" (1959, 51-2). "The contrast in colour of the soil between the raised beach level and the higher portion of the cay is not as striking as that found on Ambergris Cay, but it remains very evident. As has been noted previously, the raised beach level is best evident on the leeward side of the cay but can also be observed on the windward side" (1959, 97).

The "raised beach" is shown in Vermeer's Figure 21.

Long Cay was visited in June 1961 and the dry sand areas mapped; both Murray and I are convinced that no raised beach at the levels described by Vermeer can be demonstrated. In the first place, his description of the island as " a sand cay with a swampy depressed centre ... almost completely planted to coconut palms" gives a misleading impression of its physiography. The total area of the cay is approximately 2,525,000 square yards (525 acres); of this, only 8% is dry land. The rest is mangrove swamp and standing water. Its physiography is basically similar to that of Northern Cay: a small sandy area at the north and northwest corner, covering 22 acres, with a vast mangrove swamp to the south, with a narrow fringe of sand on its windward side. Like the mangrove rims of the Turneffe lagoons, this swamp is "hollow". From the sea one sees an unbroken wall of tall, bushy Rhizophora mangle, but much of the interior consists of open lagoon, mud, and dead and dying trees. Some of the lagoons can be seen on air photographs, and one extensive lagoon area near the middle of the cay covers about 158,000 square yards (larger than the main sand area, and 6% of the total cay area). It is thought that the area of open water is considerably

greater in the interior than is suggested by the air photographs, especially in the northern part, where, as seen from the sand area margin, there is more open water with dying trees than flourishing mangrove. A distinction is made in the map between high mangrove and more open bush; but the most flourishing high mangrove is probably restricted to the coast, and inland contains innumerable pockets of dead trees, open water and mud.

The northern sand area was traversed and mapped. It has an area of 22 acres and is trapezoidal in shape: the northwest shore, 200 yards long, parallels the southwest edge of the sand area, where it adjoins the mangrove (700 yards from shore to shore). The northeast shore is a little over 400 yards long, the west-facing shore 300 yards in length. The northeast shore is low and sandy; north of the pier there has been a little undercutting, producing a sand cliff less than a foot high. A few yards offshore there are linear banks of sand, covered with Thalassia, drying at low tide, similar to those on the west coast of Northern Cay. South of the pier the slight cliffing continues for a few yards, but is then succeeded by a broad beach of fresh white sand less than a foot above sea-level, planted with young coconuts. The northwest shore of the cay is very low-lying and fringed with a belt of Rhizophora mangle several yards wide and 200 yards long. The western shore extends from this minor belt of mangrove to the main area which forms the southern part of the cay. A substantial pier has been built midway along this shore. North of it the beach is sandy and rises to a crest 2½ feet above the sea, covered with Sporobolus virginicus. South of the pier the beach ridge reaches a maximum height of 3½ feet above the sea, and then declines southwards towards the mangrove. The average height of the sand ridge round the northern part of Long Cay is thus between two and three feet above the sea, and the maximum height not more than 4 feet. Nowhere does the surface rise to Vermeer's 5-6 foot level, and on no part of the island was the existence of "a drop of 5-6 feet to sea level" from the edge of the "raised beach" confirmed. From the low peripheral ridge the cay surface declines southwards to the mangrove and swamp areas; near the mangrove there is a fringe zone, at or near sea-level, of spongy water-soaked ground. Over most of its length, the sand area/mangrove boundary is lined with open water, forming a narrow channel separating the mangrove bushes from the sand.

Nothing was seen on the cay surface to indicate the existence of a raised beach. The surface is uniformly sandy—a coarse sand with much Halimeda, similar to that now accumulating on present beaches, and near the northwest corner, sheltered by the mangrove fringe, it is thrown up in a series of arcuate low ridges convex landward. The view of the "raised beach" in Vermeer's Figure 21 seems simply to be an area under cocal, and similar views can be seen at many points throughout the island. There is no marked break of slope on the cay surface (such as an old undercut cliff line), no raised lines of pumice or raised beach-rock, and no indication in the vegetation of such a raised beach. If such a beach can be demonstrated, then it certainly does not lie at 5-6 feet above sea-level; 2-3 feet would be its maximum elevation. I strongly doubt the existence of this raised beach and hence the conclusions drawn from it. There is nothing at Long Cay which cannot be explained by sand accumulation and mangrove colonisation at present sea-level.

The vegetation of the sandy area is of little interest. Most has been cleared for cocals, and apart from a few patches of *Hymenocallis littoralis*, *Euphorbia*, *Sesuvium* and mangroves, there is little but grasses (mainly *Sporobolus*, but some taller grasses). In the shallow water adjacent to the beach there is an abundant growth of green algae --*Halimeda* and *Penicillus* on the west side, *Halimeda* and *Acetabularia* on the east.

With a single exception there is no dry land in the mangrove area, but the exception is important. Owing to its proximity to the eastern reef, a narrow fringe of dry sand has been thrown up along a large part of the east coast, with a total length of about 1800 yards. This was traversed for most of its extent; it nowhere rises more than 2 feet above the sea, and is generally between 1 and 2 feet high. It varies in width from 20 to 40 yards, and averages 25 yards. The sand is coarse, with many shell fragments and *Halimeda*, and abundant white pumice. Much of the calcareous material probably derives from the wide eastern reef-flat, is thrown up in time of storm, and suffers little wave-sorting and abrasion, hence the number of little-damaged shells. At one point on the shore is a pile of large vertebrae of some unidentified marine animal. The ridge is planted to coconuts, with an undercover of *Sporobolus* and *Euphorbia*. It declines westwards to the mangrove swamp, and is lined at its inner edge by *Conocarpus*, *Avicennia*, and tall ancient *Rhizophora*. At many places on the seaward shore small *Rhizophora* seedlings are abundant. *Sophora tomentosa* and *Suriana maritima* were noted at one point.

A similar seaward sand ridge extends for a very short distance southwards along the east shore from the northern sand area, but because of a wide gap between it and the main sand ridge it is not possible to walk along the east coast of the island. Near the south end of the cay the eastern sand ridge disappears, and vigorous *Rhizophora* have built eastwards towards the reef: the possibility that this mangrove section formed a separate cay in the middle eighteenth century has already been mentioned. The island was circumnavigated, and nowhere else was a coastal sand ridge seen fringing the mangrove: but there are two large pockets of sand near the south end of the western shore, not large enough for coconut colonisation.

The cay has a wooden pier 55 yards long on the west side of the main sand area, with a warehouse at the end, giving anchorage in rather more than 1 fathom of water. The pier is used for the export of coconuts to Belize. The caretakers live on the northeast shore of the cay, where there is a smaller, older pier for fishing boats. Long Cay is currently owned by an American, who has built a large house with a concrete rainwater vat near the latter pier. There are two small houses on the narrow eastern sand ridge, occupied only during the *cocal* harvesting.

A note on the map

The map of this cay (fig. 35) has been largely constructed from air photographs CAE-6-178-179 and 188-190, from which derive the outline of the cay and details of the interior mangrove area. The scale

of this derivation is correct by comparison with other land areas surveyed on the same photographs (Half Moon Cay). The dry land areas were mapped by traverse in 1961, and maps drawn up on a scale of 1:2,000. These were then reduced to a common scale with the airphoto plots. In the case of the eastern sand ridge an excellent fit was obtained. The northern part of the cay on the photographs is, however, obscured by cloud, and no part of the main sand area can be seen. Hence the location of this ground map on the airphoto plot is a best-fit approximation, based on the straightness of both east and west mangrove coasts. The probable error in location of the northern surveyed portion with reference to the rest of the cay is probably no more than plus or minus 150 yards.

Hat Cay

With the single exception of Saddle Cay, only recently diminished in size, Hat Cay (fig. 36) is the smallest island on Lighthouse Reef. Speer called it "a very small round Kay" in 1771, and the description still applies; according to local informants there has been no marked change in its size or appearance for over thirty years.

It is located about 2500 yards south of the southern end of Long Cay, at the inner edge of the leeward reef-flat, here less than 500 yards wide and less than 3 feet deep. Again, like Saddle Cay, there is no clear reason for its situation at this point. The island is rectangular, and aligned NE-SW; it is 70 yards long and 55-60 yards wide. The surface is low and probably does not rise more than 2 feet above sea-level; it has a slight ridge of Acropora cervicornis shingle at the eastern end. At its eastern and western ends there are large banks of Rhizophora, partly standing in water. The rest of the cay margin is clothed with Suriana maritima and Borrichia arborescens, except for a narrow southern sand beach with Sesuvium. The cay interior contains a number of large black mangroves (Avicennia), Conocarpus erectus, and dead unidentified trees, chiefly at the northern end. There is little open ground, and what there is is covered with Sesuvium (near the sea), and Hymenocallis and Sporobolus. The area immediately to leeward of the low shingle ridge is low and marshy, though without standing water, and colonised by Avicennia.

The cay was uninhabited and devoid of wild life when visited in 1961. Pelicans are said to breed here.

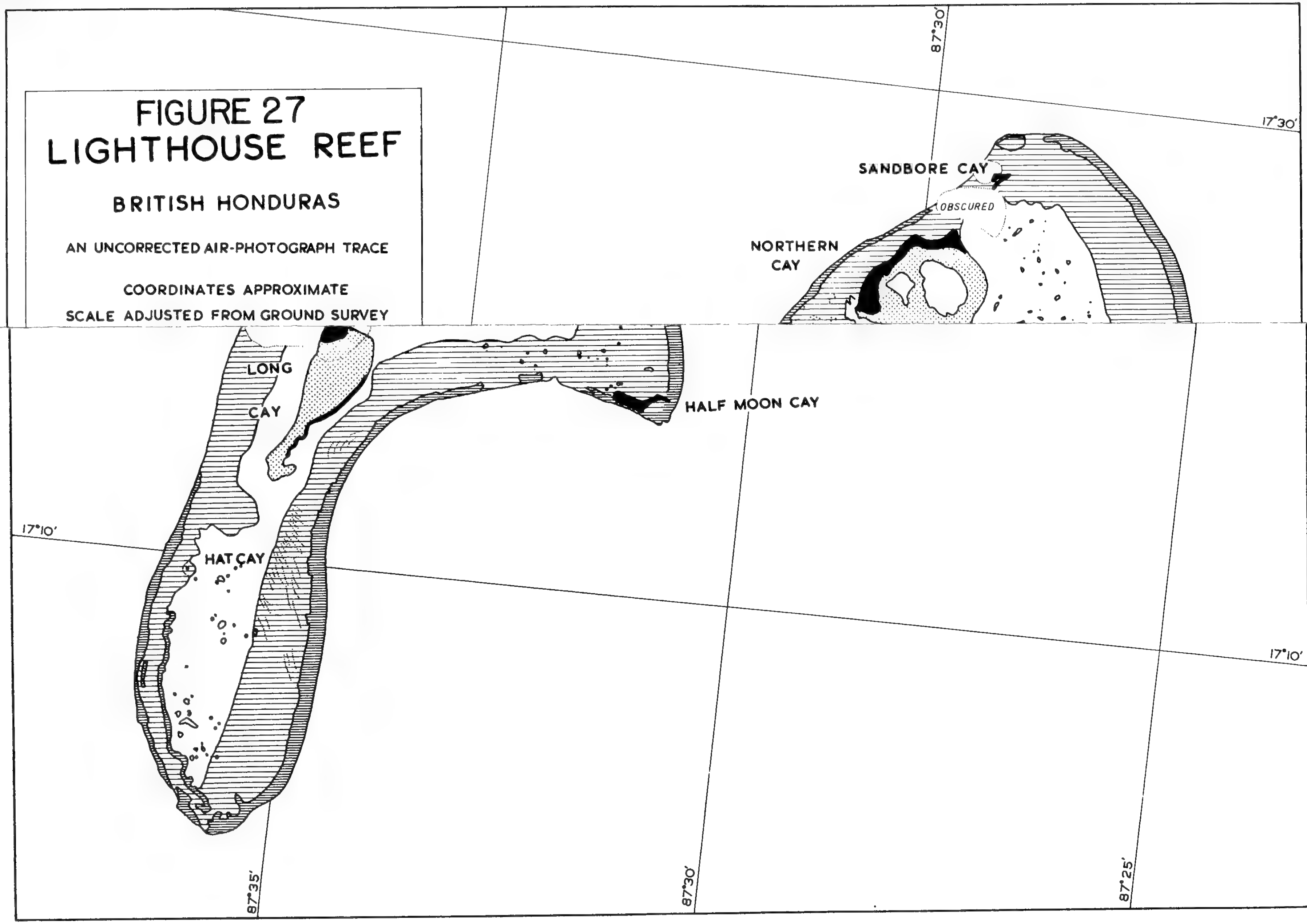


FIGURE 27
LIGHTHOUSE REEF
BRITISH HONDURAS
AN UNCORRECTED AIR-PHOTOGRAPH TRACE
COORDINATES APPROXIMATE
SCALE ADJUSTED FROM GROUND SURVEY
SANDBORE CAY
OBSCURED
NORTHERN CAY
LONG CAY
HALF MOON CAY
HAT CAY
87°30'
17°30'
17°10'
87°35'
87°30'
87°25'
17°10'

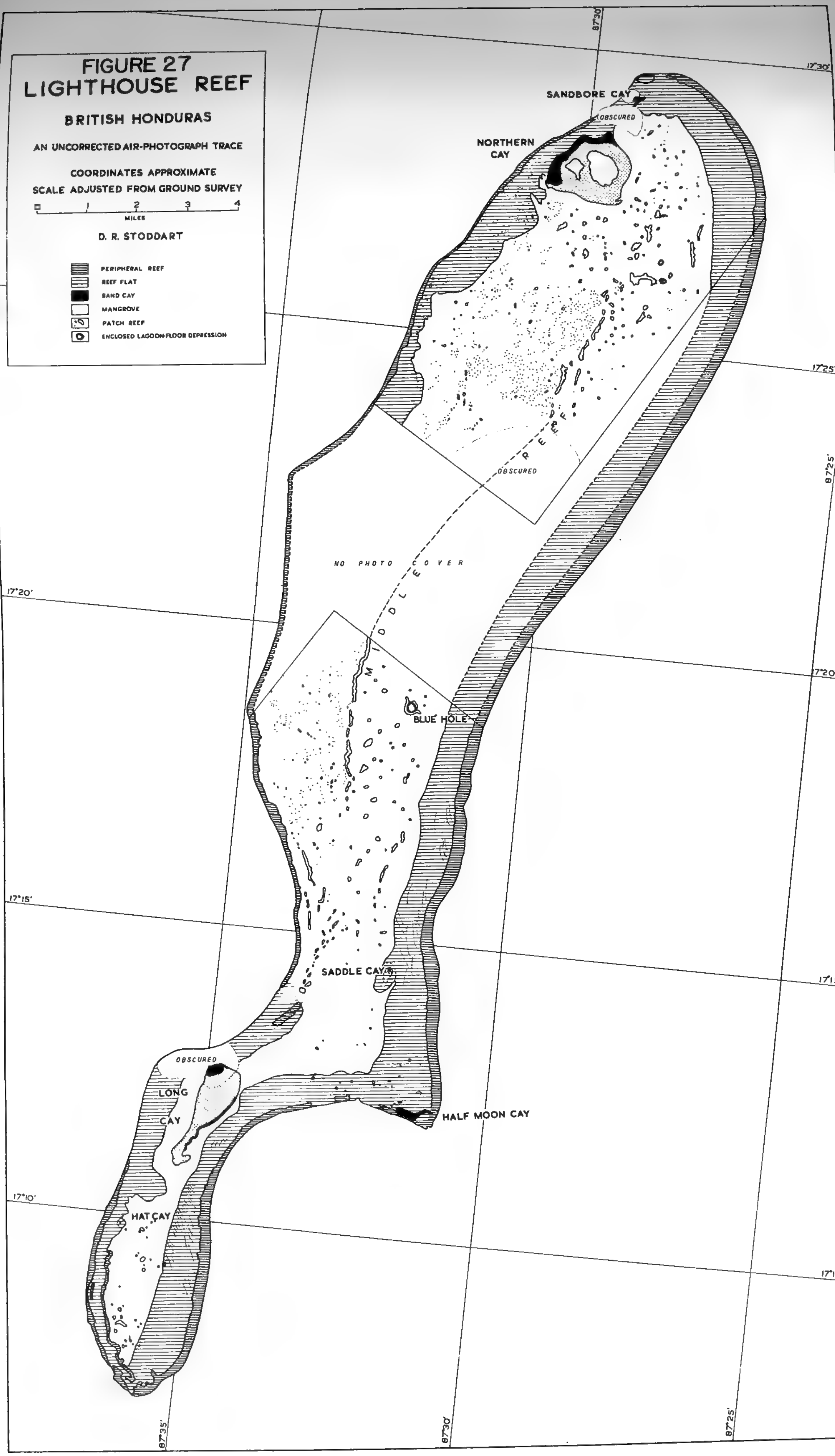


FIGURE 27
LIGHTHOUSE REEF
BRITISH HONDURAS
AN UNCORRECTED AIR-PHOTOGRAPH TRACE
COORDINATES APPROXIMATE
SCALE ADJUSTED FROM GROUND SURVEY
0 1 2 3 4
MILES
D. R. STODDART
PERIPHERAL REEF
REEF FLAT
SAND CAY
MANGROVE
PATCH REEF
ENCLOSED LAGOON-FLOOR DEPRESSION
SANDBORE CAY
OBSCURED
NORTHERN CAY
OBSCURED
NO PHOTO COVER
MIDDLE REEF
BLUE HOLE
SADDLE CAY
OBSCURED
LONG CAY
HALF MOON CAY
HAT CAY
17°30'
17°25'
17°20'
17°15'
17°10'
87°30'
87°25'
87°35'

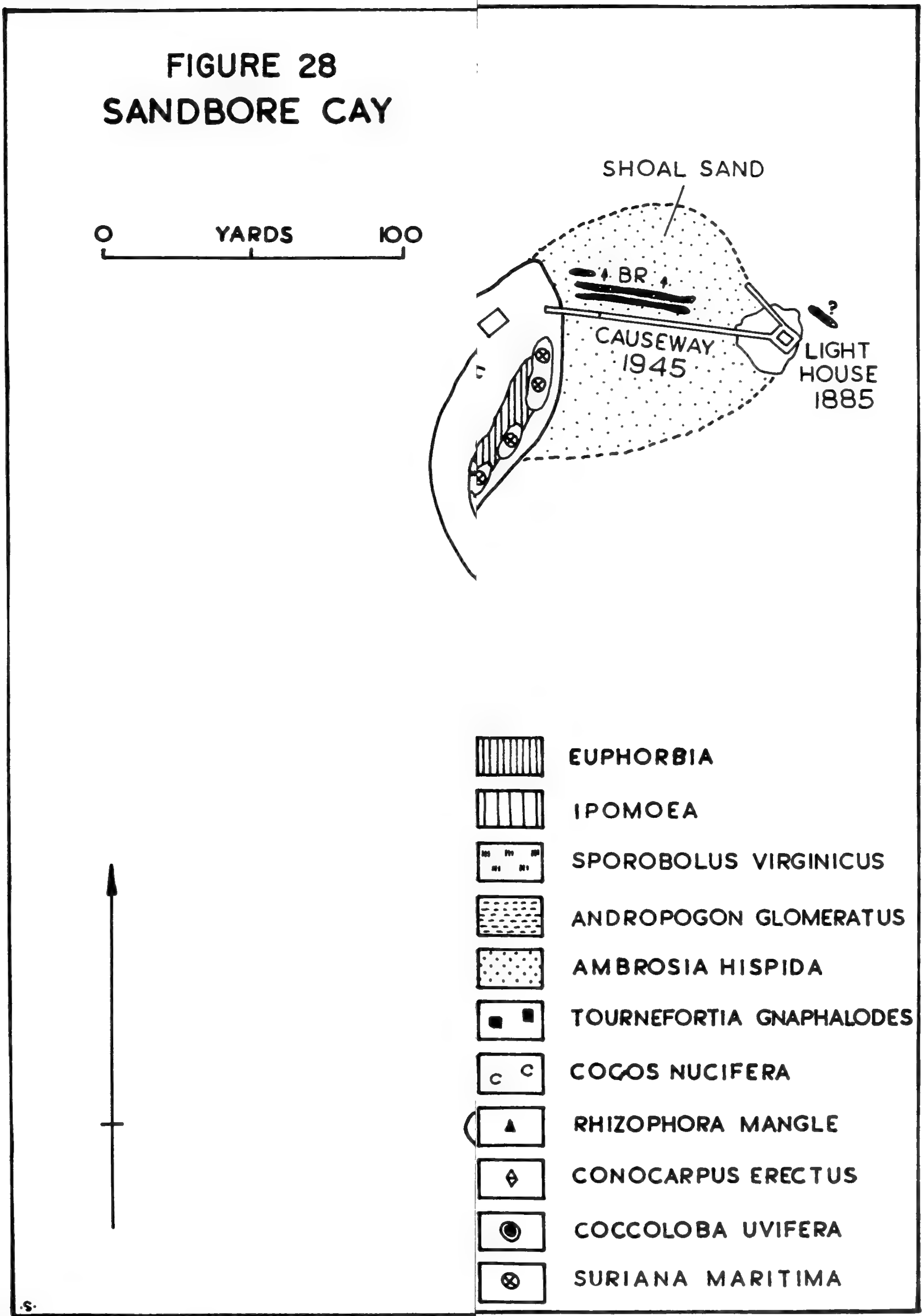
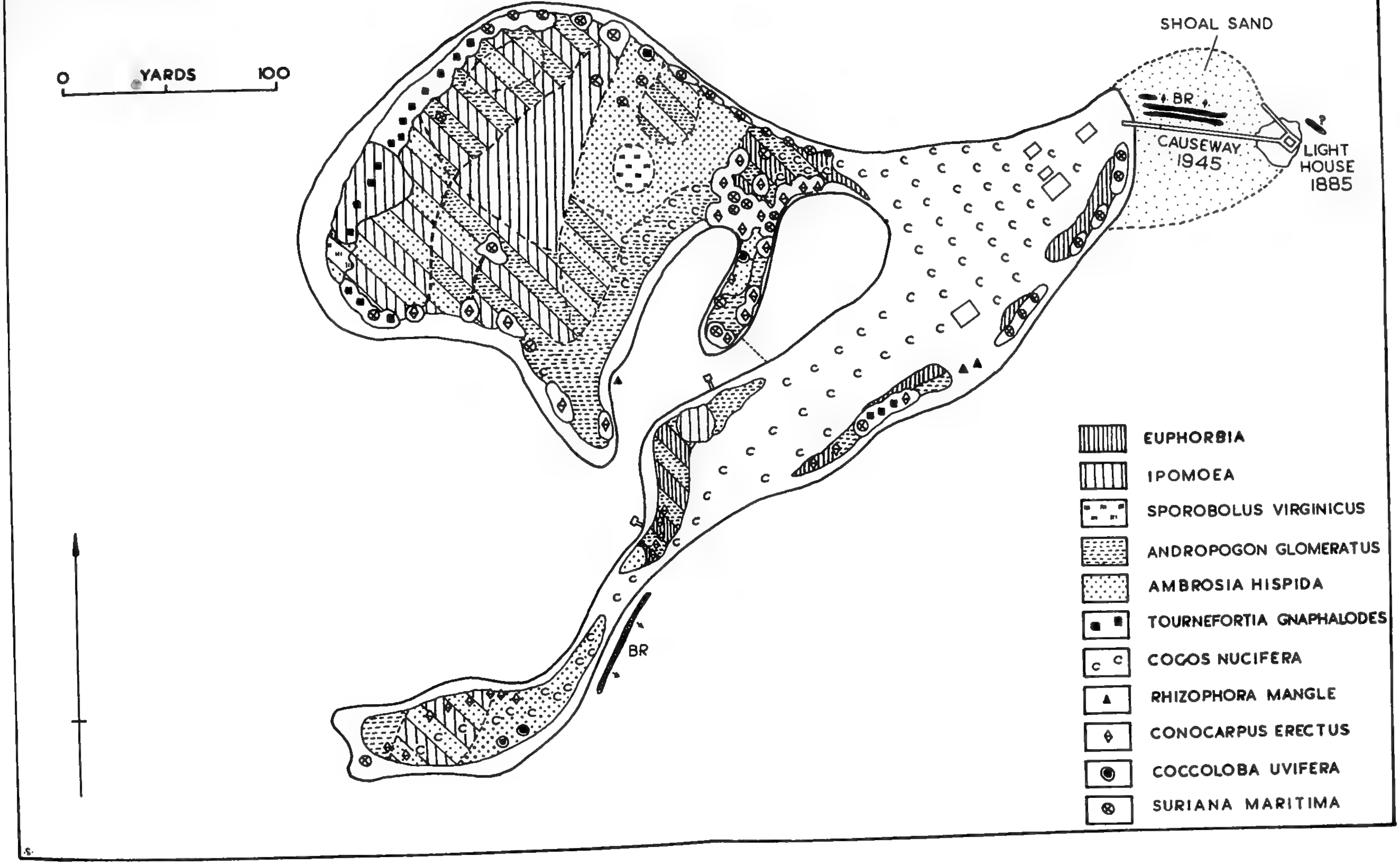


FIGURE 28
SANDBORE CAY
0 YARDS 100
SHOAL SAND
BR
CAUSEWAY
1945
LIGHT
HOUSE
1885
EUPHORBIA
IPOMOEA
SPOROBOLUS VIRGINICUS
ANDROPOGON GLOMERATUS
AMBROSIA HISPIDA
TOURNEFORTIA GNAPHALODES
COCOS NUCIFERA
RHIZOPHORA MANGLE
CONOCARPUS ERECTUS
COCCOLOBA UVIFERA
SURIANA MARITIMA

FIGURE 28
SANDBORE CAY



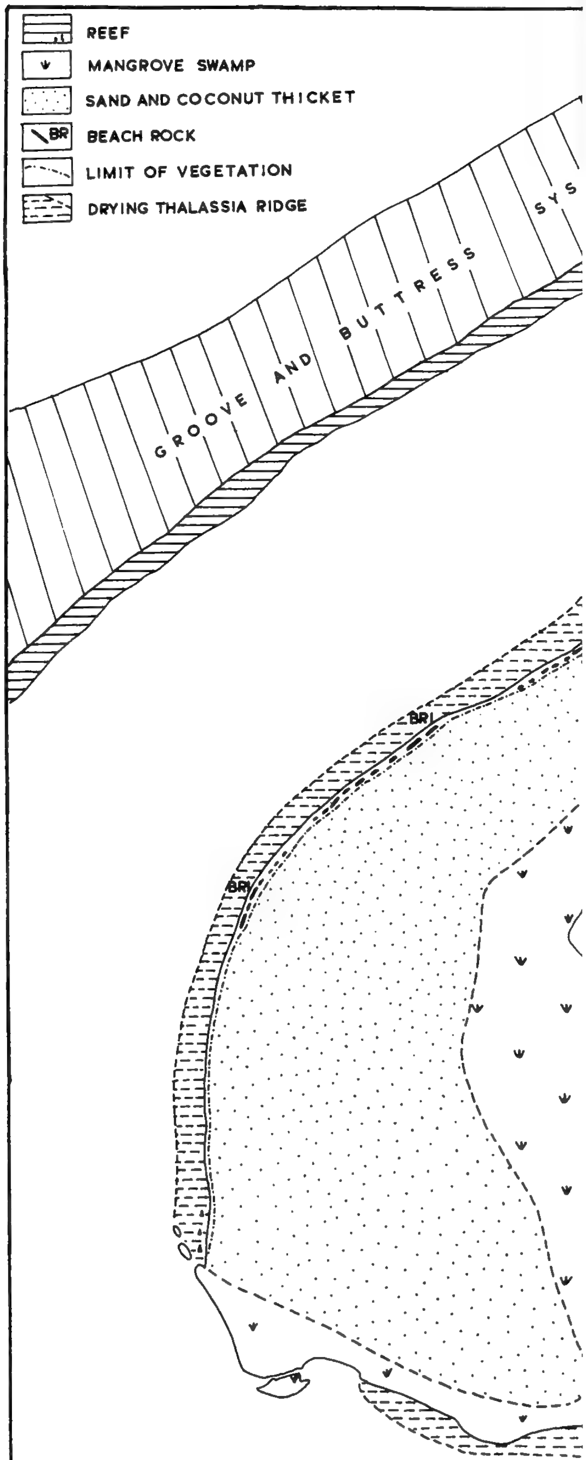


FIGURE 29
NORTHERN CAY

BASED ON GROUND TRAVERSE AND AIR PHOTOGRAPHS

0 YARDS 10

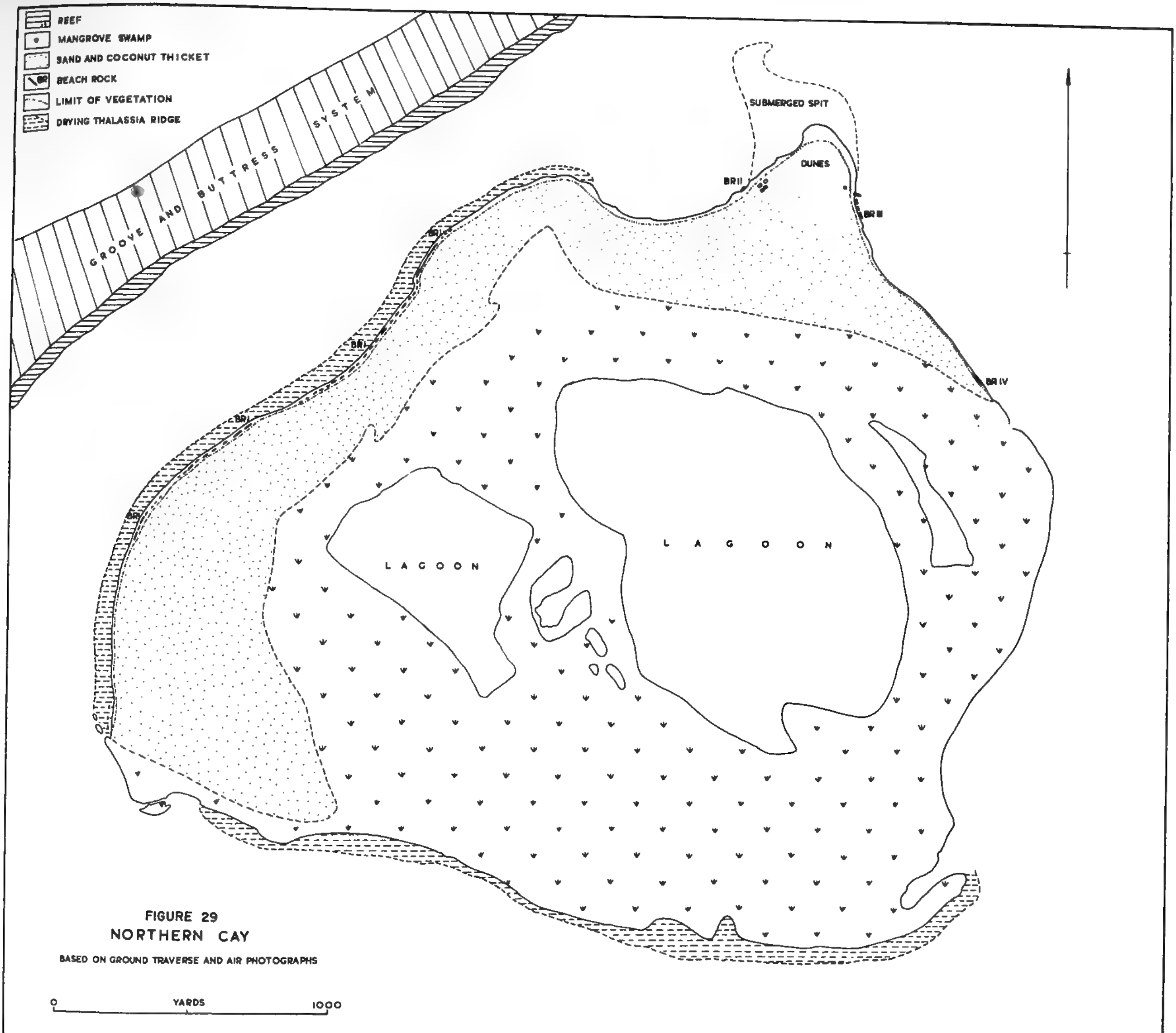


FIGURE 29
NORTHERN CAY

BASED ON GROUND TRAVERSE AND AIR PHOTOGRAPHS

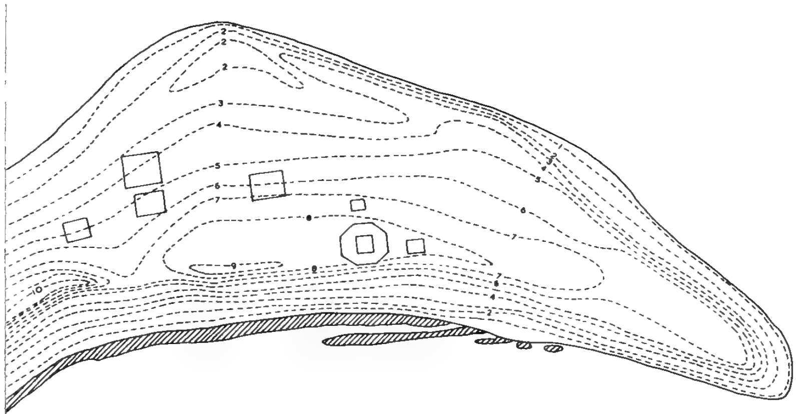


FIGURE 30
HALF MOON CAY

LIGHTHOUSE REEF

CONTOUR INTERVAL
ONE FOOT

YARDS 200

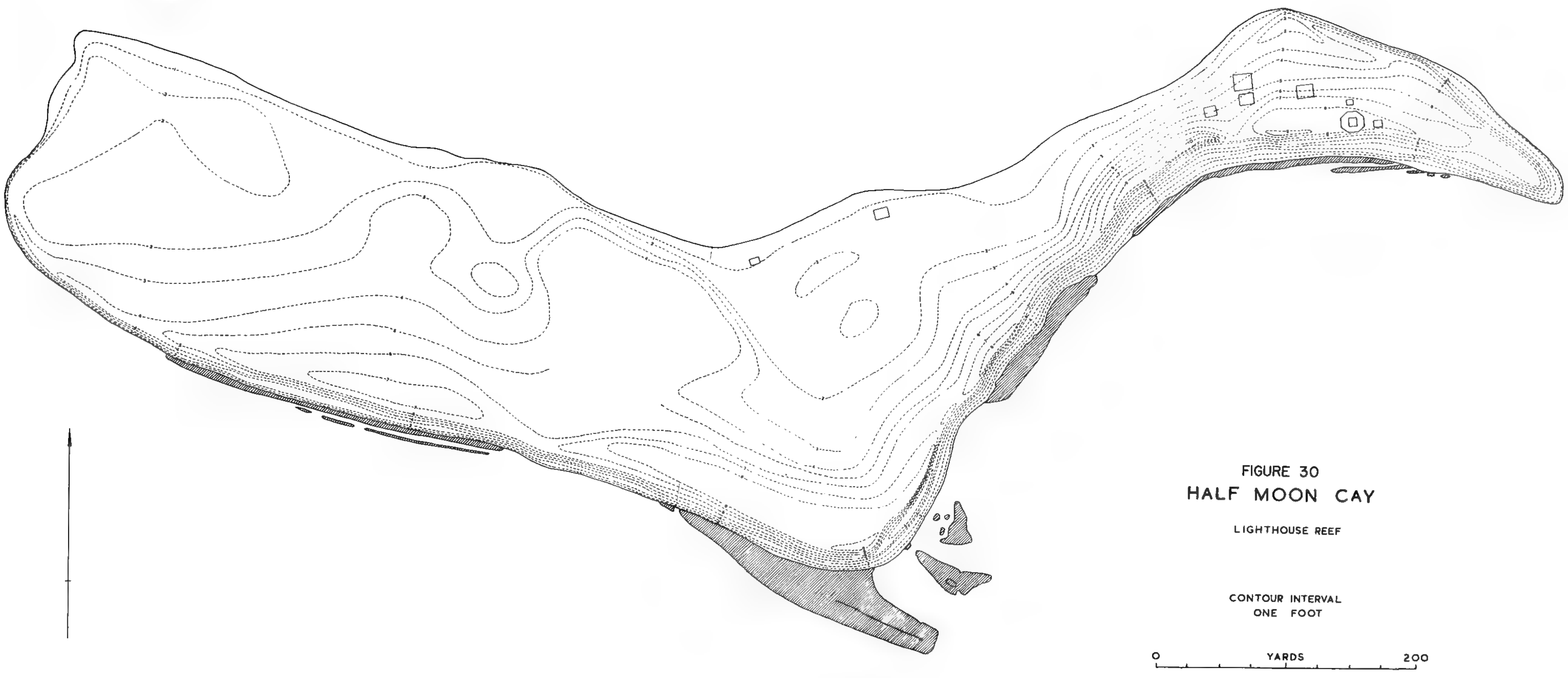


FIGURE 30
HALF MOON CAY

LIGHTHOUSE REEF

CONTOUR INTERVAL
ONE FOOT

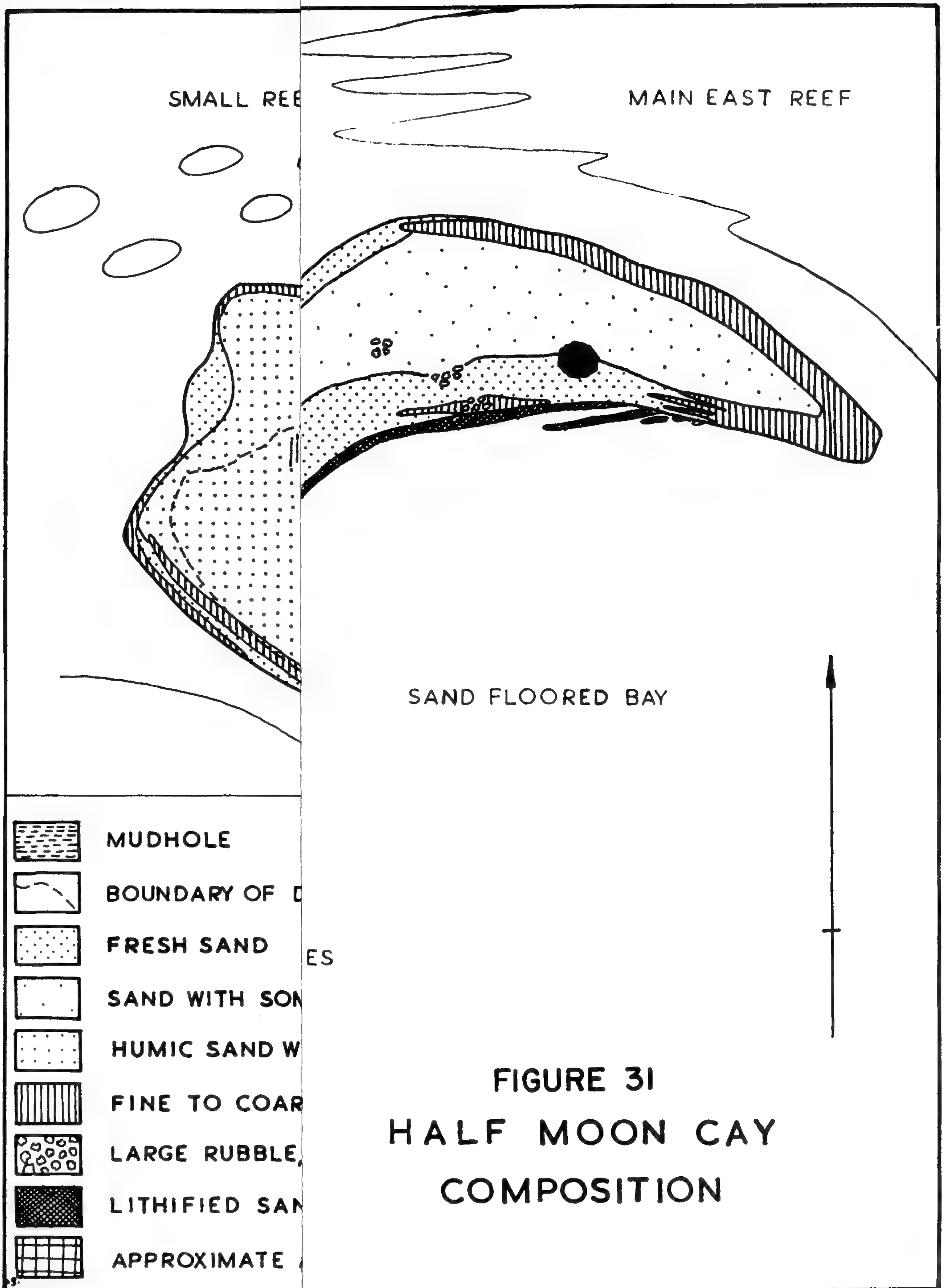


FIGURE 31
HALF MOON CAY
COMPOSITION

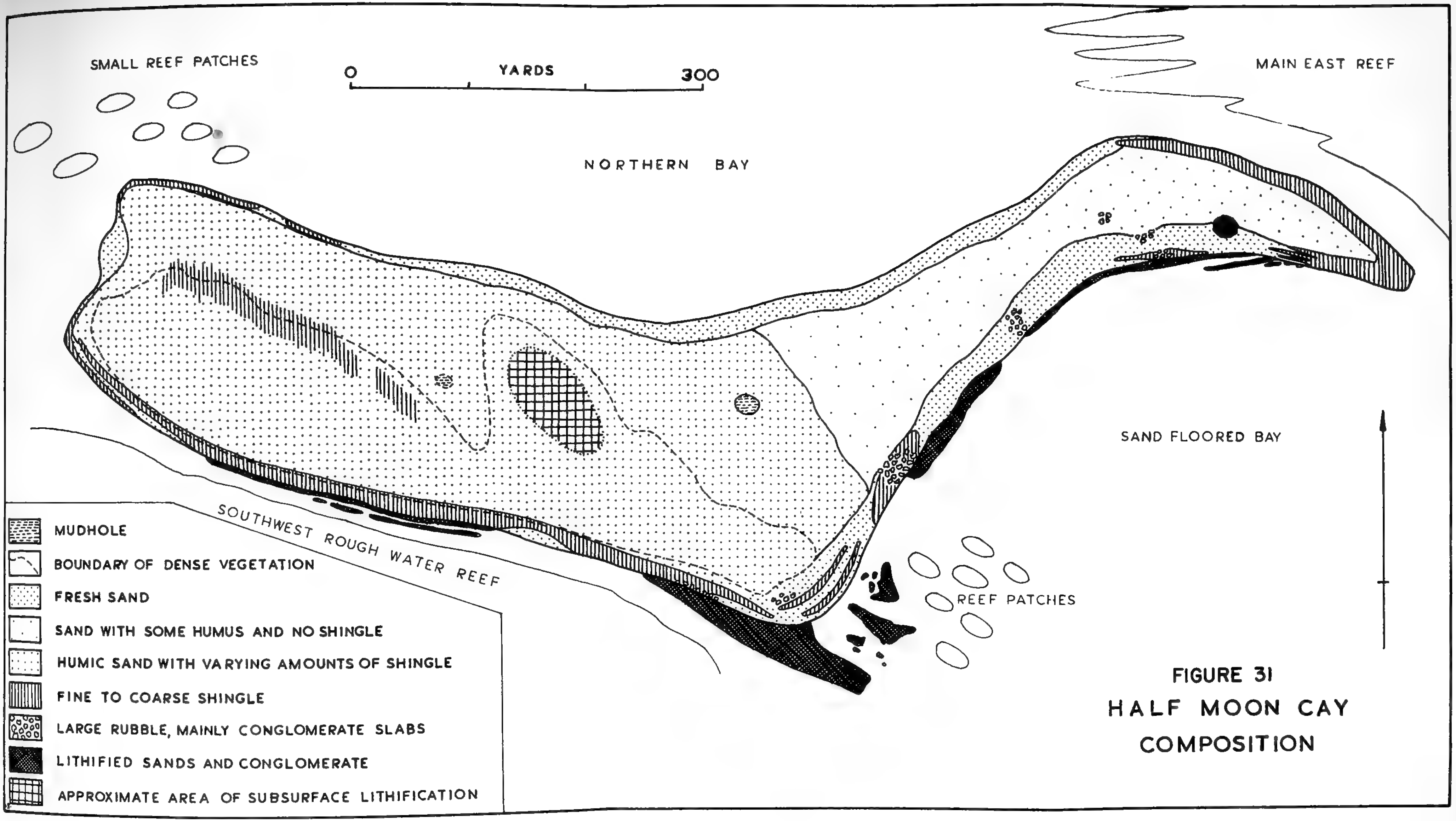
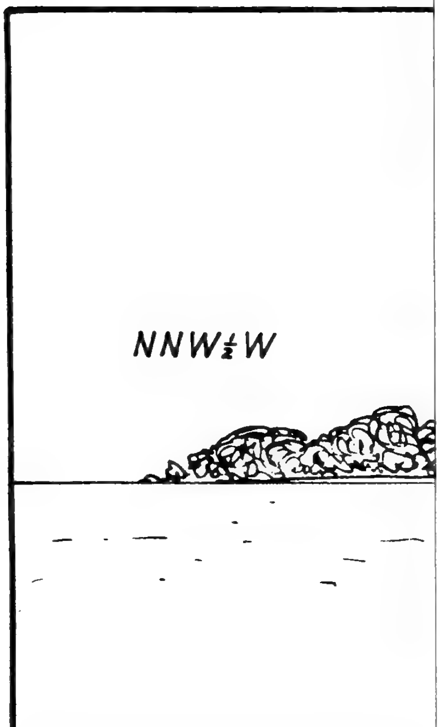


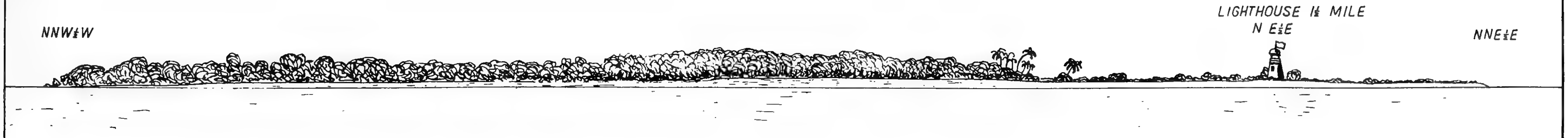
FIGURE 31
HALF MOON CAY
COMPOSITION



FROM A SKETCH PROBA

HALF MOON CAY

FIGURE 32



FROM A SKETCH PROBABLY MADE BY ANTHONY DE MAYNE, HMS KANGAROO, IN 1828

ADMIRALTY 'SKETCHES AND VIEWS', VOL. 1, 362

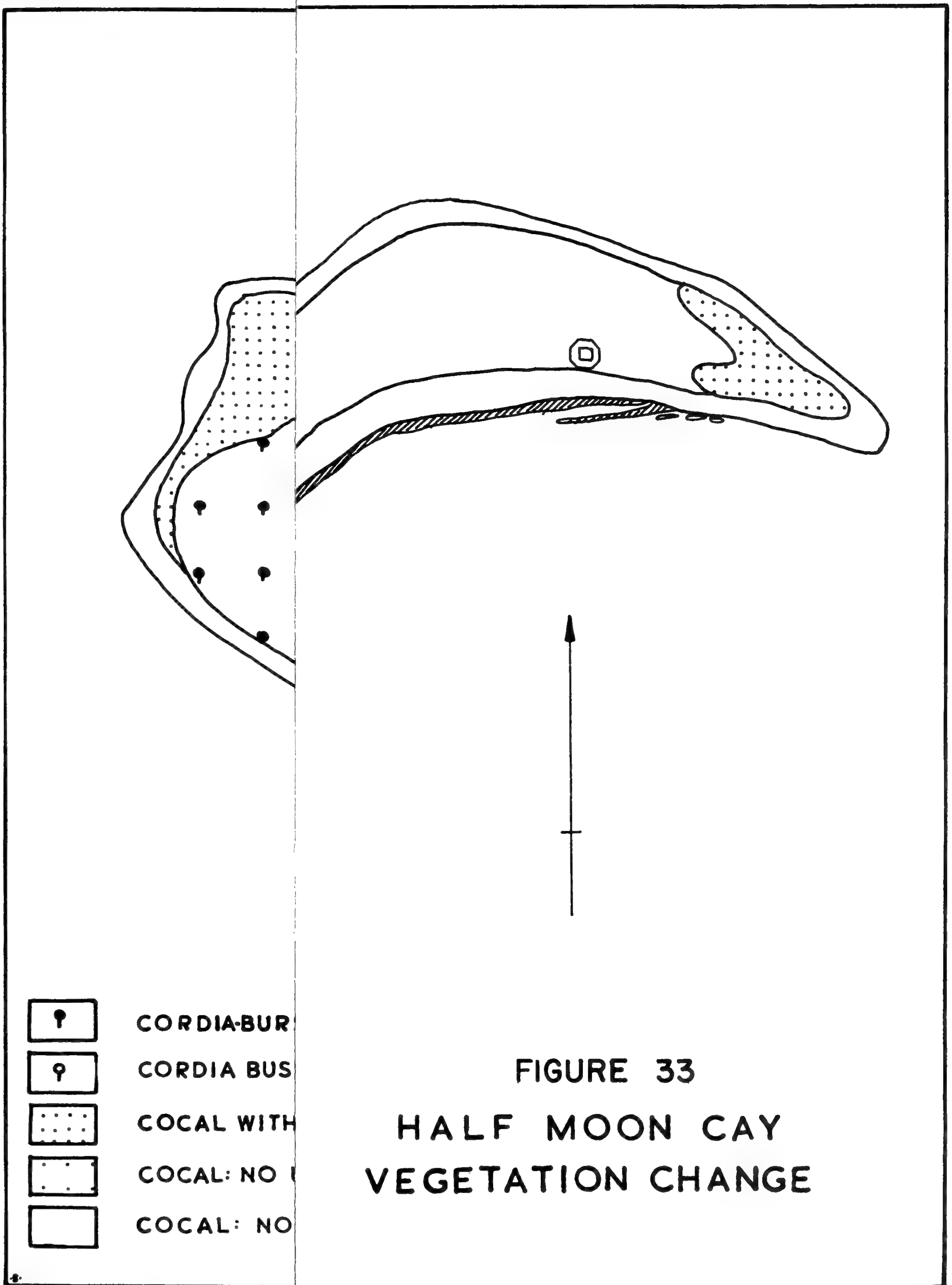


FIGURE 33
HALF MOON CAY
VEGETATION CHANGE

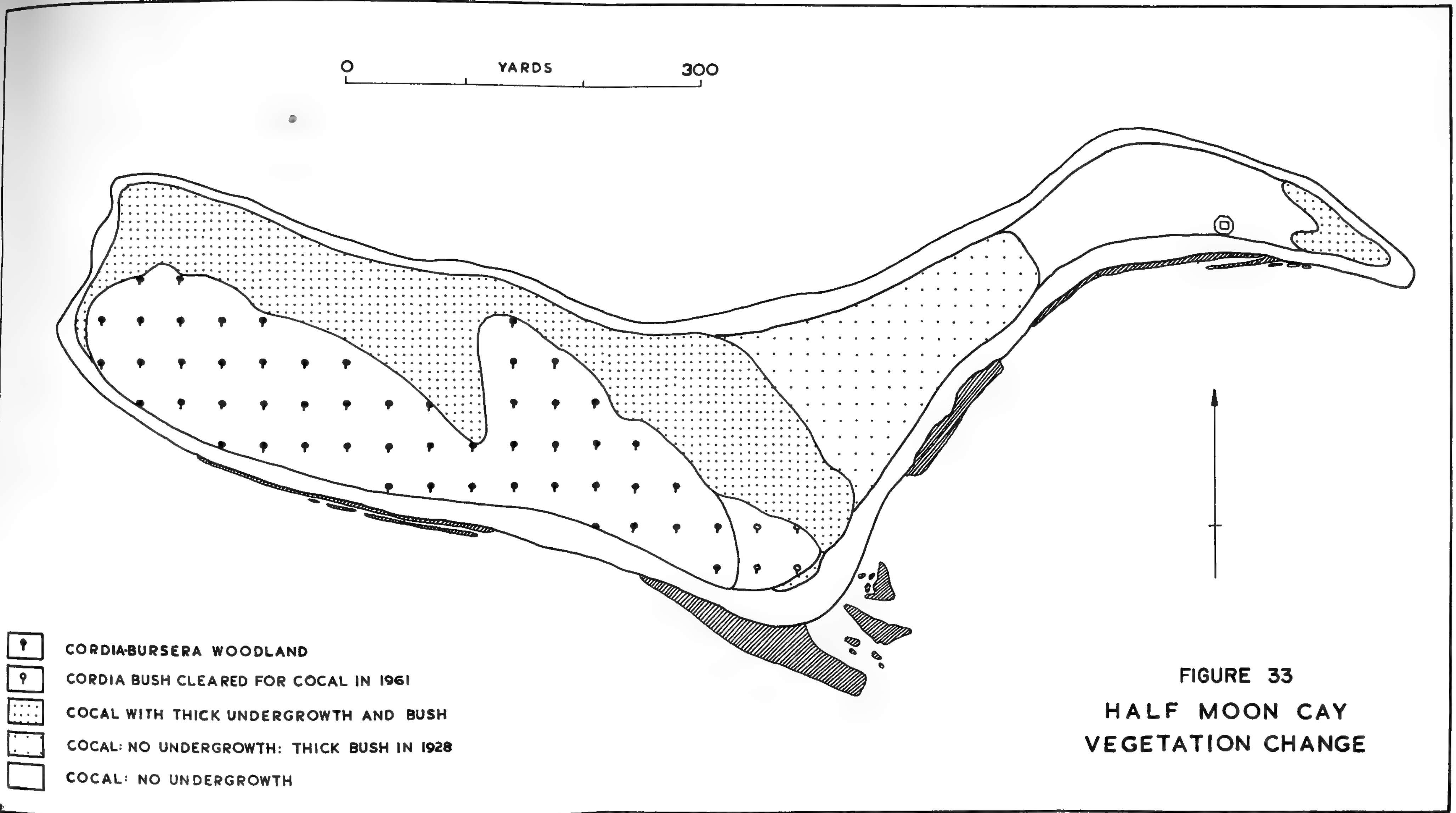


FIGURE 33
HALF MOON CAY
VEGETATION CHANGE

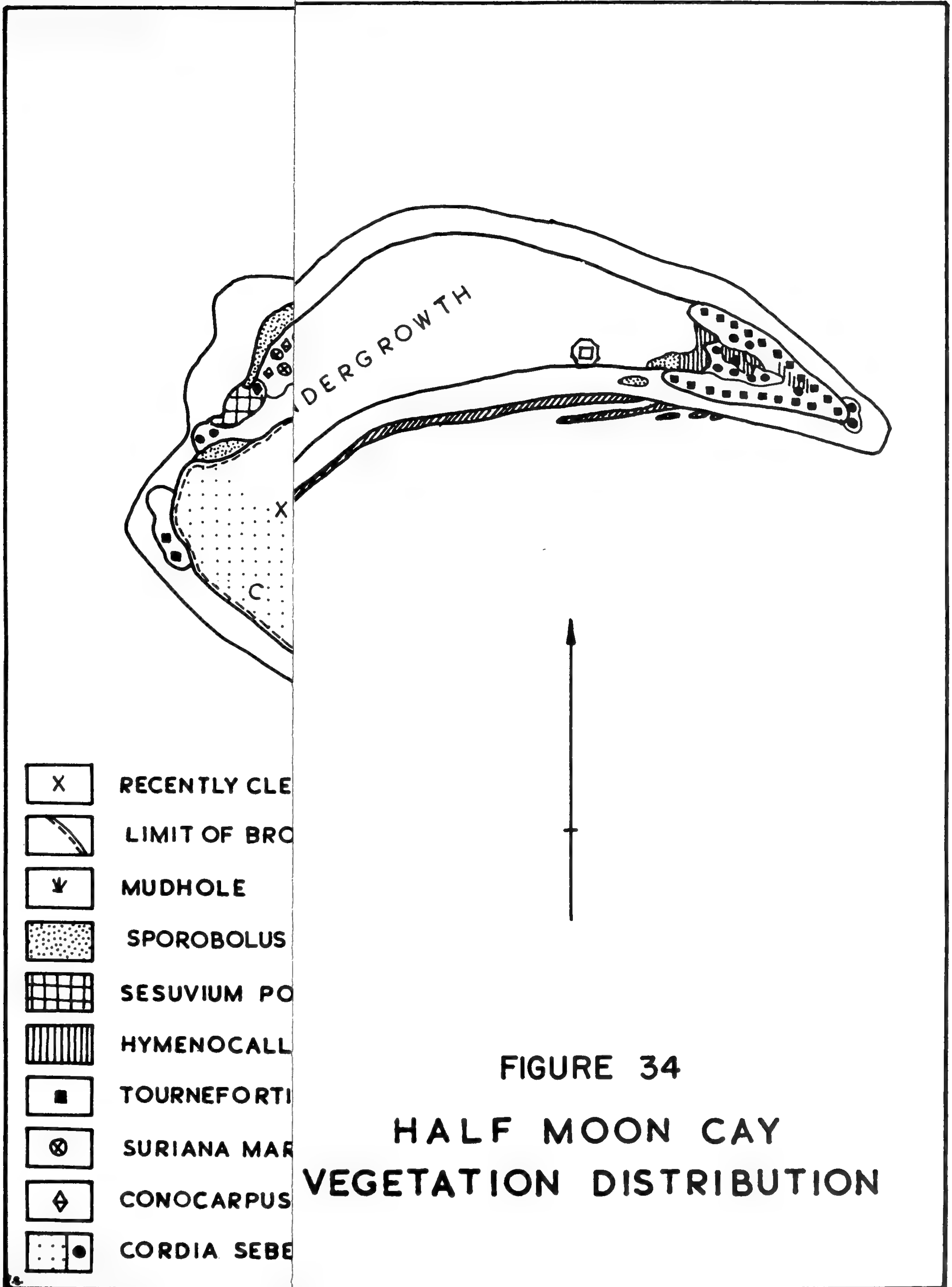


FIGURE 34

HALF MOON CAY
VEGETATION DISTRIBUTION

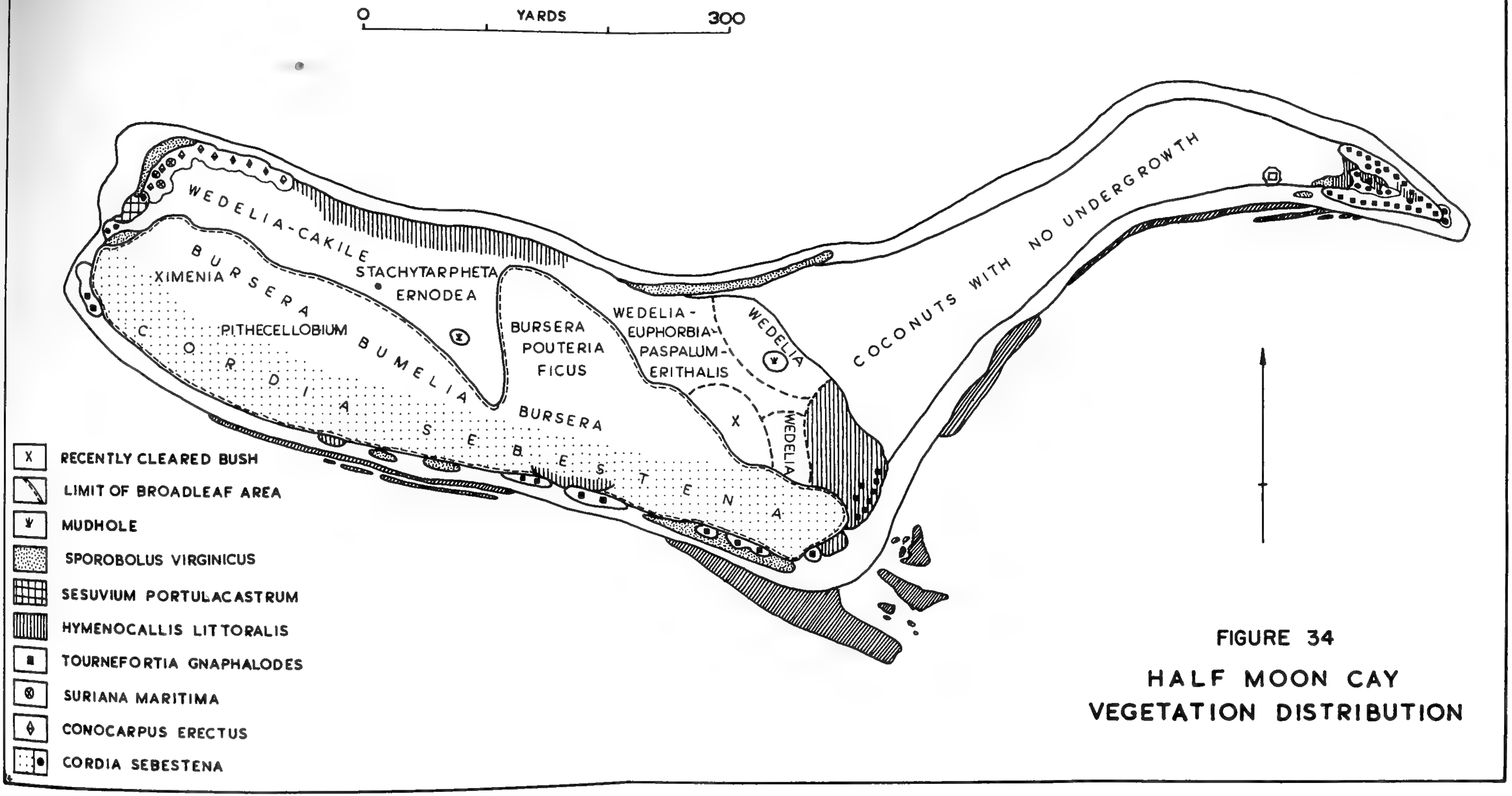
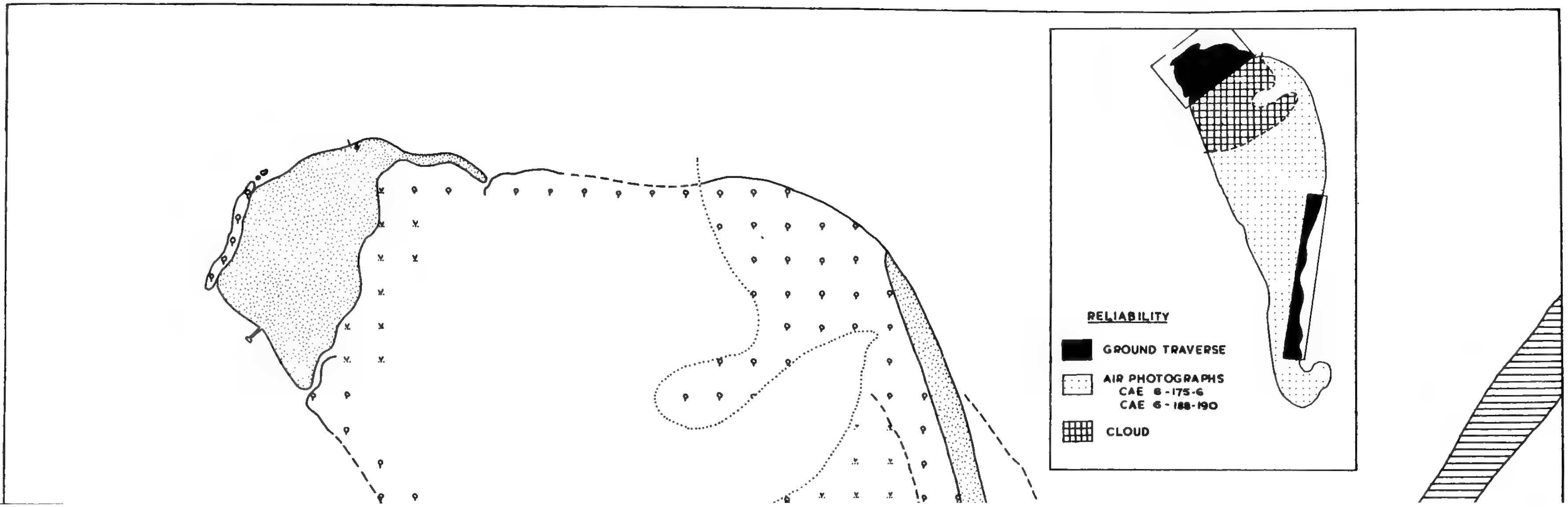


FIGURE 34

HALF MOON CAY
VEGETATION DISTRIBUTION


RELIABILITY
GROUND TRAVERSE
AIR PHOTOGRAPHS
CAE 6-175-6
CAE 6-188-190
CLOUD

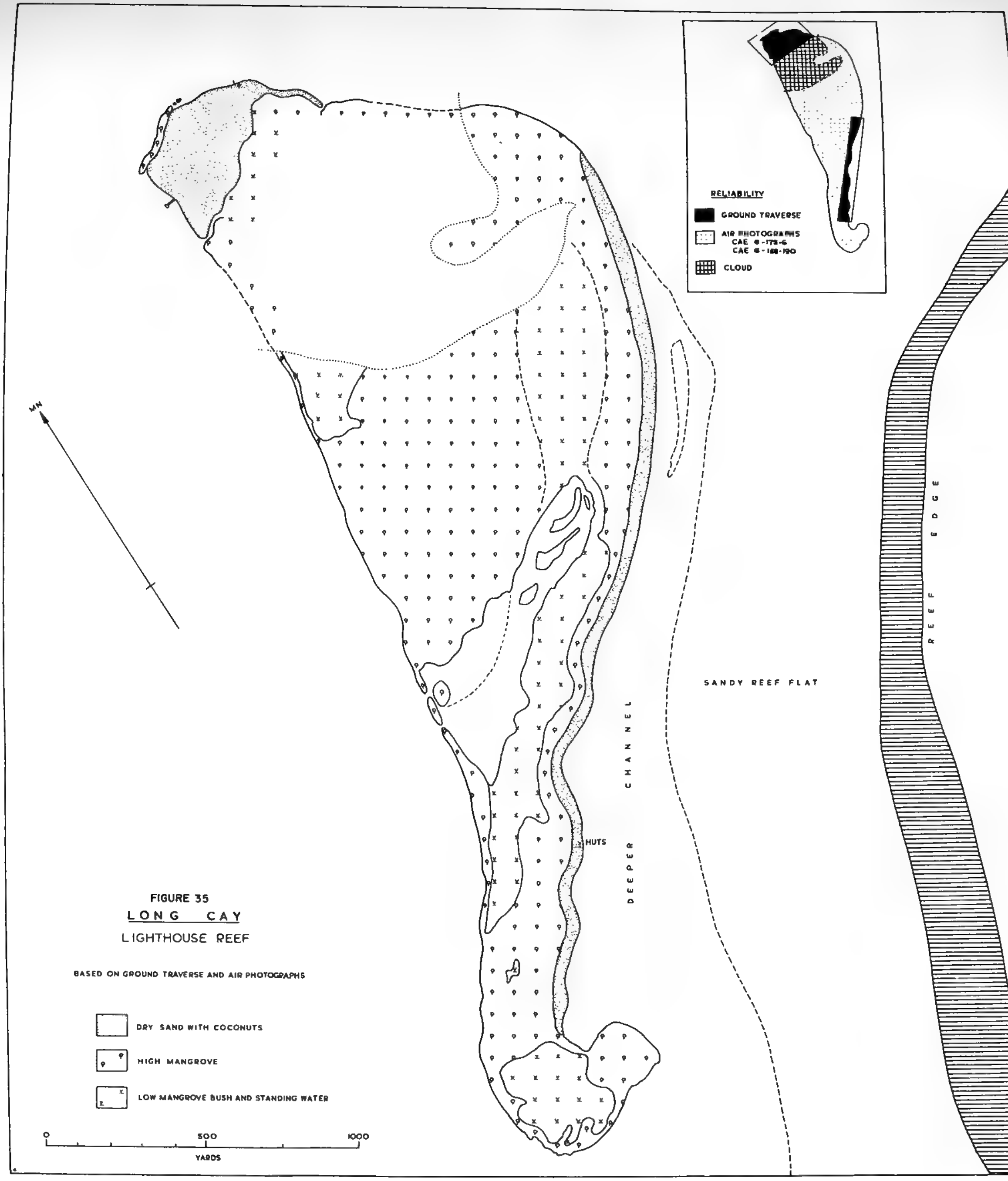
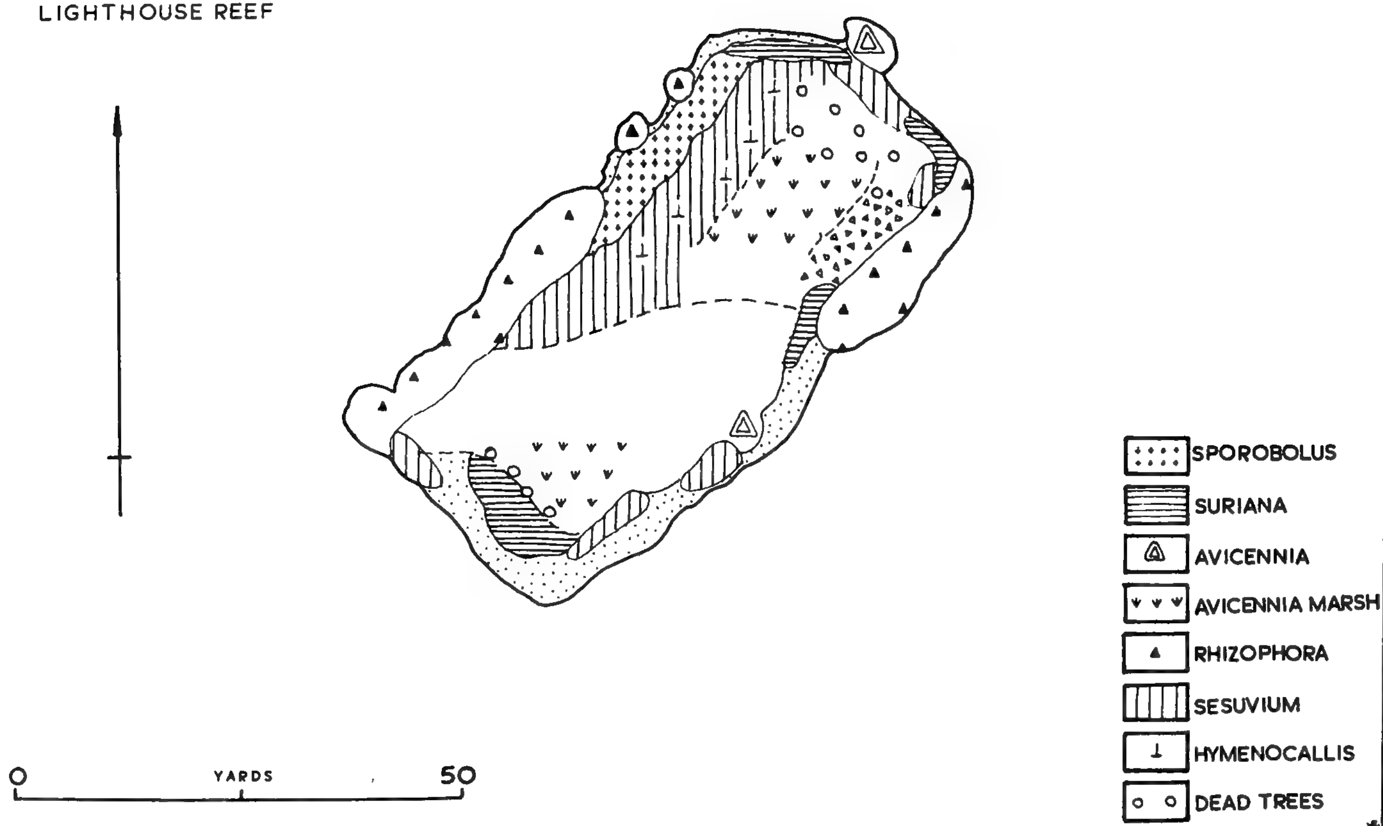


FIGURE 35
LONG CAY
LIGHTHOUSE REEF

FIGURE 36
HAT CAY

LIGHTHOUSE REEF



VII. GLOVER'S REEF

The greatest length of Glover's Reef (cf. Vermeer, 1959, 19-20) is 15 miles and its greatest width $6\frac{1}{2}$ miles. With an approximate total area of 81.6 square miles it is slightly larger than Lighthouse Reef but much smaller than Turneffe. The atoll (fig. 37) is surrounded by broad, well-defined reefs of living coral breaking surface (transects C and F), interrupted by three prominent gaps. The largest of these is Southern Entrance, one mile wide and carrying 1-2 fathoms water; it provides good anchorage for small boats. Northern Entrance, on the windward side of the atoll near its northern extremity, is some 1400 yards wide, with similar depths, opening into an extensive shoal area with numerous coral heads. The third and smallest entrance, also on the windward side, lies between Northern Cay and Long Cay. It is only a quarter of a mile wide, and a heavy swell surges through it continuously; no information can be given as to its depth. As already noted, small fishing boats can thread their way between coral heads to cross the leeward reefs in one or two places, but there are no interruptions of the reef platform on the leeward side. This restriction of the gaps to the windward side is anomalous; on many Pacific atolls there is a strong negative correlation between wind-direction and reef-gap location, though this is not perhaps as widespread as might be supposed (Emery, Tracey and Ladd, 1954, 142-143; Newell, 1956, 326-327). According to Newell, "The passes mark old gaps in the atoll rim where organic accretions evidently have not kept pace with the general upward growth during subsidence....the distribution of passes may in some way be controlled by prevailing winds." (1956, 326-327). As shown in this paper, there is no necessity in the case of the British Honduras atolls to invoke subsidence, though this is far from denying that it may have taken place; and it has been shown that subsidence on a large scale has taken place on many Pacific atolls (Emery, Tracey and Ladd, 1954, 74-91; Ladd and others 1953), and in the Bahamas (Spencer, 1951). The interpretation followed here is that the reefs have grown up in post-glacial times on structurally-controlled foundations. The reason why the gaps should be confined to the windward reefs, during such development, while the leeward reefs are virtually continuous, remains unknown.

On one point, however, the reefs agree with general atoll experience, in that the zone of living coral on the reef-flats is wider on the windward than the leeward sides. The reefs of Glover's Reef may be considered to fall into four groups, on the basis of width and orientation:

(a) the northern reef, facing north: the reef-flat here has an average width of about 500 yards, and judging from air photographs it is coral-covered for one-third of its width.

(b) the eastern reef, between Northern Entrance and Northern (or Northeast) Cay, facing east: the width of the flat varies here from 500-1400 yards, and averages some 1100 yards. The width of the zone of growing coral remains fairly constant at about one-third of a mile.

(c) the southeast reefs, from Long Cay to Southwest Cays, facing southeast: the flat there is much narrower, from 200-500 yards wide, with a fringe of coral 100 yards wide at its outer edge.

(d) the leeward reefs, facing WNW, with a fairly constant reef-flat width of 4-500 yards, increasing to 6-700 yards in the south.

The width of zones (a) and (b) is clearly related to the prevailing north and east winds. The southwest reefs are narrow, in view of their windward location, but this may be explained by the fact that they are aligned sub-parallel to the winds, rather than transverse to them. Ecologically they are more comparable to the main east reef (transect C), rather than to leeward reefs of similar dimensions (transect F). The reef-flat back of the zone of living reef sinks lagoonward and carries 2-6 feet of water. Wherever seen, its surface consisted of loose foraminiferal, algal and coral sand, sparsely covered with green algae and *Thalassia*. No rock platforms were seen back of the living reef area.

The bathymetry of the lagoon enclosed by the reefs is very inadequately known, though some soundings were made in the southern third of the lagoon in 1961. Plans to sound down the centre of the lagoon were abandoned because of adverse weather. Taking the soundings, air photographs, and local information together, the following picture emerges. The reef-flat is bounded lagoonward over most of its extent by a submerged platform with an average width of one mile. The limits of this platform can be well seen on air photographs, and are shown on the atoll map. The platform appears sharply bounded lagoonward by a steep slope to the lagoon floor, and seaward by a steep rise to the present reef-flat. Line soundings in the southern part of the lagoon showed that on both windward and leeward sides it has a depth of 3-4 fathoms. The significance of this platform at such a depth will be discussed later, but attention is here called to the presence of a very similar feature, hitherto undescribed, along the British Honduras barrier reef. Here a platform extends 1-4 miles lagoonward of the present reef-flat at depths of 2-4 fathoms. No comparable submerged platform is seen on Turneffe or Lighthouse Reef, since the lagoon floors do not fall below these depths.

The lagoon itself is unique in the three atolls because of its depth and the very numerous patch-reefs and pinnacles rising to its surface. On the very limited data available, the lagoon appears to be basin-shaped, with depths of 10-12 fathoms near the sides and 17-20 fathoms in the centre. Local informants, found in all other instances to be accurate, stated that the maximum depth of the lagoon, found near its geographical centre, is 24 fathoms. Some 700 reef patches rise to the surface from the lagoon floor, not counting those on the 2-4 fathom shelf or the reef-flat proper, and some of these are as much as 500 yards long. Most are roughly circular, with coral growth on the east and north sides (transect G); a number are elongate, with apparently random orientation, but similar living-reef distribution. The basin-shaped lagoon shoals towards its northern and southern parts, and the greatest concentration of patches is found in the deepest central area. This is in apparent contradiction to the fact that in the Pacific most reef patches are found in the shallowest lagoons (Cloud, 1957; Nugent, 1946, 744-745). The number and density of reef patches in the Glover's Reef lagoon is much higher than on Lighthouse Reef. Attention may be called to the 'chain' of large patch-reefs orientated north-south near the lagoon centre, which recalls some of the north-south chains of patch-reefs in the Barrier Reef lagoon, the north-south Middle Reef of Lighthouse Reef lagoon, and the north-south "ranges" of cays in the Turneffe lagoon.

There is no information on the nature of the lagoon floor. For some reason (possibly the depth of the floor) the conspicuous downwind attenuation of patch-reefs by debris trails found, for example, by Newell on Raroia (1956, 353-355, Plates 29-30), is not seen on Glover's Reef (though Raroia lagoon reaches greater depths than Glover's Reef). In no single instance was a patch-reef or outer reef seen with dry elevated reef-rock, similar to that found intermittently on Lighthouse Reef, which suggests that whatever cause gave rise to the Lighthouse Reef drying patches was limited to that Reef alone.

Land fauna of Glover's Reef

Schmidt (1941) records only two reptiles from Glover's Reef, collected by the Field Museum Mandel Caribbean Expedition in 1940, but gives no location details. They are *Anolis sagrei* Dumeril and Bibron, and the wish-willy, *Ctenosaura similis*. *Ctenosaura* was seen frequently in 1961 on Northeast Cay, Long Cay and Middle Cay. *Iguana iguana*, known on Half Moon Cay, Lighthouse Reef, was not seen during our brief visits to Glover's Reef.

Salvin appears to be the only ornithologist to have visited Glover's Reef, in 1862, and he recorded (1864) *Columba leucocephala* (bald-pate pigeon) on Middle Cay, and *Pelicanus occidentalis* (brown pelican), *Sterna antillarum* (lesser tern), and *Thalasseus regius* (a larger tern) from Long Cay. On Southwest Cay II, he found "Noddies everywhere....many thousands in all", while eggs of Sooty Terns "might be gathered by the basketful" (1864, 383). The nesting birds on this cay are named as *Anoüs stolidus* and *Anoüs minutus* by Bond, who did not however visit this reef. He comments: "I was told that this colony had greatly diminished in size. Since this islet is the only known breeding ground of *A. minutus* in the entire Caribbean area and the only locality where *A. minutus americanus* Mathews has been reported, it would seem advisable to establish a bird sanctuary here" (1954, 6). This has not so far been done. At the request of Dr. G.H. Lowery of Baton Rouge, we confirmed the existence of this colony of white-capped brown noddies (*A. stolidus*?) on this cay in 1961, but certainly not in the profusion described by Salvin. The whole cay is under coconuts, and the noddies appear to nest in their crowns. They are seen in large numbers flitting over the water at dawn and dusk, but it is difficult to approach them on the cay. According to fishermen they vary greatly in number throughout the year.

Other birds seen in 1961 included a few brown pelicans at Northeast and Middle Cay, a single osprey (*Pandion haliaetus*) at Northeast Cay, and a pair of frigate birds (*Fregata magnificens*) at Middle Cay. Salvin recorded the brown booby, *Sula leucogaster leucogaster* Boddaert, between Glover's Reef and Cay Bokel. There are two specimens of the flycatcher *Elaenia martinica chinchorrensis* Griscom from Middle Cay in the Carnegie Museum, Pittsburgh (known from Lighthouse Reef and Chinchorro Bank), and specimens of the hummingbird *Anthracothorax prevostii prevostii* from Middle and Northeast Cays, also in the Carnegie Museum (Todd, 1942, 294). One species (a small white gull?) was seen nesting on the small

island northeast of Long Cay in May 1961, laying its eggs in small excavations on bare sand about two feet above the sea, at the leeward end of the cay. There were two eggs to each nest, each about 3/4 inch long, silver-grey in colour and speckled dark brown, extremely difficult to see against the sand background. Seven species of birds were thus seen by Salvin (the seventh is the mockingbird Mumus gilvus leucophaeus Ridgway); Elaenia and Anthracothorax make nine; and the osprey and frigate birds seen in 1961, eleven.

Of domesticated animals, there are some black pigs and chickens on Long Cay, and pigs on Middle Cay. Hermit crabs are found in large numbers, especially on Northeast Cay, but it is not known whether rats are a common pest to coconuts on any of these cays.

The cays of Glover's Reef

There are at present six cays on Glover's Reef, all on the southeast side. Five of these (Northeast, Long, Middle, and Southwest I and II) are of a large size, ranging from 330 to 1100 yards in length; while the sixth, Long Cay North, is a smaller island 160 yards long north of Long Cay. All are formed of clastic reef material, and no solid rock, apart from beachrock, outcrops on any of them. Some confusion has been caused by the insertion on published Admiralty charts of a further cay lying within the lagoon on the west side of the reef, 4 miles from the northwest corner of the atoll (Chart 1797 of 1929); it is described as having trees 20 feet tall. This cay is mentioned again in the West Indies Pilot, 1956, 459-60. According to Vermeer, who "viewed it at a distance from the air", "towards the centre of the lagoon a solitary cay, which appears to be covered with mangrove, rises from the bank to breach the otherwise continuous expanse of water" (1959, 19). This cay does not now exist, and has not existed for many years. No local fisherman with knowledge of these waters can remember seeing it, though the location of the island is known (bearing Northeast Cay 130°, Southwest Cay II 180°, uncorrected compass bearings), near a small gap in the leeward reef. The site was visited in 1961, and carried 3-4 feet of water; occasionally an ephemeral sandbore breaks surface. The site is known as "Bushy Spot" or "Bushy Cay". It is interesting that Owen in his MS chart of 1830 (H57) shows no cay at this point: so that the cay marked on the charts must have accumulated, been vegetated, and swept away, some time between approximately 1830 and 1930. It should be erased from charts.

Detailed maps were made of the cays on the southeast rim, and descriptions of each of these cays are given here. It might be noted that in Owen's 1830 MS chart, two small sandbores are marked between Middle Cay and Southwest Cays which have now disappeared. Vermeer (1959, 19) describes seeing "at the northern edge, two sand ridges, visible at some distance"; these do not break surface, though they may occasionally form ephemeral strips of dry land, as in fact happens in similar circumstances along parts of the Barrier Reef, for example north of Tobacco Cay.

Northeast Cay

Northeast Cay (fig. 38) is situated at the southern end of the unbroken east reef of Glover's Reef, on the north side of the entrance between Northeast and Long Cays. The cay is semi-circular in shape, 330 yards long along its near-straight northern shore, and with a maximum north-south width of 200 yards. The physiography of the island is basically simple: a shingle ridge rises steeply on the south and southeast sides, protecting a gently-sloping surface of sand and gravel, which falls away to the north shore. The shingle ridge begins in a few yards from the shore on the east side of the cay, about 100 yards from its northeast corner. Small coral-blocks and white rubble top the sand beach on this side of the cay, but the sand beach gives way southwards to a shingle shore. The shingle ridge on the southeast side is a double feature: grey and blackened older shingle and small coral-blocks form a layer one foot and more in thickness, overlying an undercut and eroded formation of grey sand at least $1\frac{1}{2}$ feet in thickness. In front of this lies a fresh ridge of white, relatively unworn coral fragments, heavily encrusted with _Homotrema rubrum_. The newer ridge is 3-4 feet wide, and rises to a height of 2 feet; it can be traced without interruption round the base of the older shingle ridge for over 300 yards. It is separated from the older ridge by a slight depression, and there is an undoubted difference in composition between the two ridges. The older ridge consists mainly of grey and blackened sticks of _Acropora cervicornis_, slabs of _A. palmata_, and small individual coral colonies, generally more than 4-5 inches long. The new ridge consists of smaller coral fragments, chiefly _A. cervicornis_ sticks comparable to those in the older ridge, though fresher, together with large quantities of _Halimeda_, including still-segmented fronds, a considerable proportion of _Lithothamnion_ nodules, well-preserved conch shells (_Strombus_ sp.), and tests of echinoids.

The whole shingle ridge complex averages 5 feet in height, with an estimated maximum of 6-7 feet nearest to the living reef at the southeast corner of the island. Along the south shore it is somewhat lower, decreasing to 5 feet in 150 yards westwards, and then more rapidly, to 3-4 feet, along the southwest shore. With the decrease in height, the size of the constituent material decreases, and the newer ridge becomes less important. The shingle section at the southeast corner seems to show considerable erosion at this point after the formation of the old ridge and before the formation of the new. The greater part of the old ridge has here been removed, leaving only its landward feather-edge overlying sand, across which the shingle ridge had been advancing at the time of its destruction.

At two places on the south shore, beachrock extends seaward from beneath the shingle ridge. Both outcrops are sandy, poorly consolidated, and dip seawards, indicating a slight shift of the shore northwestwards, away from the reef. Small blackened, rotten coral blocks and slabs of small size litter the reef-flat along the base of the shingle ridge on the southeast side.

The evidence of shore retreat shown by the shingle section and the beachrock is further reinforced by the character of the northeast shore, immediately north of the end of the shingle ridge. The sandy shore here consists of small bays separated by bluffs 1-2 feet high, outjutting 2-3 feet, and generally carrying individual coconut palms. The small headlands are being gradually undercut, and in some cases, at least on the surface, appear to consist now of a tangle of roots with little clastic debris at all, all the finer material having been flushed out by the waves. Many of the coconut trees have fallen, with a remarkably constant direction normal to the shore (compass bearing 55-65° east of north), which may suggest hurricane damage. Undercutting on this scale is limited to this segment of the cay shore.

The other shores of the cay, to north and northwest, are low and sandy, with intermittent scatterings of fine coral shingle. Vegetation approaches close to the sea, and no active progradation or degradation seems to be in progress. A submerged sand-spit is building out from the northeast point into the shallow northern bay, the bottom of which is largely covered with Thalassia. Short choppy seas are found in this bay during moderate easterlies.

The interior of the cay has little of interest physiographically, with the exception of a mudhole toward the east side, located in the lee of the higher shingle ridge. No standing water was seen in this hole in 1961 (May and July), and the black soil was largely covered with a ground mat of Wedelia trilobata. The greater part of the cay surface consists of dirty grey sand and some fragmented coral colonies. The windward shingle ridges form a band some 10 yards wide on the south and southeast shores, and immediately landward there is another zone, 10-15 yards wide with an indefinite landward edge, of what McKee (1956, 8-9) would term "rampart wash", or a surface layer of shingle-size debris.

The vegetation of Northeast Cay is of interest. Most of the island is covered with coconuts, with a ground cover of Wedelia, Euphorbia, Ambrosia or grasses, but near the southeast side is an area of tall broadleaf woodland, comparable to that at Half Moon Cay, Lighthouse Reef. Near the shore this consists of Coccoloba overlooking Tournefortia, but inland, in addition to Coccoloba, there are tall trees of Bursera simaruba, Ficus ovalis (?), Neea choriophylla, and a palmetto (Thrinax parviflora(?)). The undergrowth in this area consists of Ambrosia, Wedelia, and the grass Eragrostis domingensis, which here reaches a height of 6-7 feet. The seaward-facing shores of the cay are lined mainly with Tournefortia, with a little Suriana and a number of small trees of Cordia sebestena; the leeward shores are covered with low Sporobolus and Sesuvium, with Conocarpus and Erithalis bushes at the northwest point.

Long Cay North

Between Long Cay and Southwest Cays the southeast reef of Glover's Reef extends without break in a NE-SW direction. Long Cay and Long Cay North are located at the northeast end of this reef, south of the gap

between the southeast reef and Northeast Cay. Looking towards Long Cay from Northeast Cay, one sees the coconut covered area of Long Cay proper, with two low, bush-covered areas in front. One of these is a peninsula extending from the northeast corner of Long Cay; the other is an island, here designated "Long Cay North", separated from Long Cay by a narrow deep channel which allows heavy seas to roll in from the reef-flat. This smaller island is known locally simply as "sandbore".

Long Cay North (fig. 40) is approximately 160 yards long, widening reefwards to a maximum width of over 50 yards. The main body of the cay is prolonged westwards (lagoonwards) by a narrow, curving 50 yard long spit of brilliant white sand. Water 2-3 fathoms deep is found within a few yards of the northwest point on both its north and south sides. The greater part of the cay is built of ridges of coarse, unconsolidated white sand. There are no hard-packed shingle ridges, but fresh white shingle is scattered over the sand surface, and forms a ground cover, particularly at the east end. There are no large blocks, either on the cay or immediately offshore. The beach ridges are not more than 2 feet high, and the maximum height of the cay is probably not more than 3 feet at any point. The western sand-spit decreases in height lagoonwards until it is washed over by waves approaching from each side at high tide. The whole spit is probably awash in storms. The shape of the cay is adjusted to wave-refraction patterns in the two adjacent gaps, as shown by the sketch-map of observed patterns. At the extreme east end of the island, the interior is formed by small rubble, fringed by a new white sand beach a few feet wide. This in turn is margined seawards by a low ridge of fine white debris comparable to that described at Northeast Cay. The island bears no sign of great antiquity, and was not noted by Owen in 1830 (MS chart H57).

The main body of the cay at the eastern end is covered with a compact thicket of vegetation, of which the bay cedar, Suriana maritima, is the dominant member, forming bushes 10 feet high, which in places are wind or spray trimmed. The only other trees are a number of Conocarpus erectus bushes, and one or two small coconuts on the southeast shore. At the exposed east end of the cay, and intermittently along the north shore, are clumps of Tournefortia gnaphalodes, and in May 1961 a a number of tiny Tournefortia seedlings were advancing westwards along the sand spit. The ground beneath the Suriana, and round the fringes of the vegetation thicket, is covered with Sesuvium portulacastrum, some grasses, and Euphorbia. A single specimen of Sophora tomentosa was seen on the south shore, but not in flower.

No beachrock is exposed round the cay margins.

Long Cay

Long Cay (fig. 41) is situated near the northeastern end of the southeast reef; it is a long, narrow island, aligned with its long axis parallel to the reef, and has many features of interest. The cay is 680 yards long along its main axis, which ranks it among the largest sand cays on this coast, and is roughly hour-glass shaped: the width

decreases from a maximum of 130 yards in the west to 70 yards in the centre, increasing again to 160 yards near the eastern end. The addition of a low, bush-covered peninsula, similar in appearance to Long Cay North, at the northeast end of the cay, gives a maximum north-south width of nearly 250 yards at this end of the cay. The south shore is fairly straight and overlooks a shallow, boulder-studded reef-flat, with waves breaking on living reef only 30-40 yards from the shore. The north shore forms a broad, arcuate embayment, terminated by lagoonward projections at both ends.

The dominant physiographic feature of this cay is the massive development of shingle ramparts on the seaward side, which cannot be matched on any other island on this coast. The main features of the rampart can be seen from the map and section. The ridge begins at the southwest end of the island as a mound of small shingle and scattered coral blocks up to 2 feet in diameter. Already at this point the ridge is a double feature--an inner mound of blackened debris, and an outer lower ridge of glistening white, *Homotrema*-encrusted small coral and nodular *Lithothamnion*. In the slight intervening depression there is a cover of *Hymenocallis littoralis* growing directly on the shingle. The whole ridge system rapidly rises to a height of 5 feet on the southeast shore, where again the seaward face of the inner ridge is formed of grey-white interlocking shingle, chiefly *Acropora cervicornis* sticks and *A. palmata* slabs, with a fresh white ridge at its base. From its crest the surface dips slightly inland, and presents a barren expanse of rough, blackened coral blocks, generally between 6 inches and 2 feet in diameter. Some 30 yards inland (20 yards from the first major crest) a second blackened ridge of coarse, broken blackened blocks rises above the backslope of the first (fig. 43). The material composing it seems coarser than that composing the first ridge, and much coarser than that composing the depression between the two crests. It is also considerably older, as shown not only by the degree of blackening of the constituent coral (Teichert, 1947), but also by the breakdown of the coral blocks themselves. Many of these, notably *Montastrea annularis*, are breaking down by subaerial radial fracture, first into large segments of the original colony, then into cuboidal fragments averaging 1 inch across, and then into constituent limestone grains.

As these two ridges are followed eastwards the crests move together and the intervening depression becomes less pronounced; the two ridges can, however, be clearly traced along the whole length of the shore, both topographically and by debris characteristics. The outer ridge has a fairly constant altitude of 5-6 feet at its crest; the inner ridge at the line of section reaches nearly 9 feet and may exceed 10 feet near the eastern end. North of the second crest the debris decreases in size fairly rapidly and gives way to grey sand. In places, there is a distinct step-like margin on the north side of the inner ridge, as though the shingle had been pushed back over a pre-existing sand surface. The total width of this shingle complex averages 50 yards, and in places is nearly twice that figure. Locally it occupies one third or even one half the width of the cay. Along the east shore, the ridge sinks rapidly to 2-3 feet above sea-level, and the calibre of the material comprising it also decreases.

Along most of the length of the cay the surface falls relatively rapidly from the shingle zone to the north bay, and is composed of dark sand and small fragments of rotted coral. At the east end, however, protected by both the eastern and the southern shingle ridges, a depression has been formed in the center of the island, occupied by a sheet of still, stagnant water approximately 80 yards long and 40 wide. This pond is surrounded by an apron of soft, rich brown humic soil, which may at times be flooded. The whole of the depression containing the pond, which lies approximately at sea-level, is 120 yards long and 80 wide; it was impossible to survey it in detail or to excavate because of the intense mosquito infestation.

Northwards, as has been noted, the island is prolonged by a low peninsula similar in appearance and size (120 x 50 yards) to Long Cay North. Long Cay has been inhabited by a single aged negro for 31 years, and according to him the peninsula is only intermittently connected to the cay, but nothing was seen in the physiography to support this. It is formed mainly of coral rubble, with a ridge structure on the east side, sheltering an area of white sandy beach to the west. The maximum height of the ridge is 2-3 feet. Coconuts are not found on this peninsula, and the vegetation (fig. 42) consists of a thicket of _Suriana maritima_, _Conocarpus erectus_, and low bushes of _Tournefortia gnaphalodes_. Again, the resemblance to Long Cay North is striking. A small pond has been dammed up at the northern extremity of the peninsula by the shingle ridge.

The whole of the north shore is low and sandy, fronting a shallow bay, the floor of which is thickly carpeted with _Thalassia_. With the exception of the shingle ramparts and the northeast peninsula, the natural vegetation has been removed from the whole of the cay for coconut plantations. Over much of the island, beneath the coconuts, there is now only a sparse and intermittent ground cover of _Euphorbia_ and grasses. Much of the shingle area is completely barren, except for clumps of _Tournefortia gnaphalodes_ and _Coccoloba uvifera_ on the seaward side, and some patches of _Hymenocallis littoralis_. The more diversified vegetation of the northeast peninsula has already been described. Even the stagnant water and marshy flat at the east end of the island has been cleared of distinctive vegetation, except for some small _Conocarpus_ round its edges. The whole of the cay, with these exceptions, is covered with dense _cocal_, with much coconut trash forming a patchy ground cover. A couple of palmettoes were noted near the south end.

There is an outcrop of beachrock at the southeast corner of the cay, where a rock promenade extends for over 100 yards along the shore and continues beyond the cay shoreline for another 40-50 yards. The exposure here is strikingly similar in distribution to that at the southeast corner of Half Moon Cay, Lighthouse Reef. The rock dips to the SSE, and varies in width from 3-5 feet. Along its landward edge there are a number of erosional remnants rising above the general level (which is close to mean sea level) for 6-9 inches. There are two lines of this beachrock, parallel to each other, with water 2-3 feet deep between.

There are several huts on the cay, which is permanently inhabited by a caretaker who keeps the _cocals_ cleared. Fresh vat water is available.

Middle Cay

Middle Cay (fig. 43) is located near the centre of the southeast reef of Glover's Reef, without any marked reef entrance or gap nearby. The island is of fairly simple outline, and aligned NE-SW, parallel to the reef. It is 450 yards long, and increases in width from 120 yards near the southwest end to 240 yards in the northeast. Recurved spits are found at both northeast and southwest ends of the island, projecting lagoonward.

The seaward shore rises above a narrow, shallow reef-flat, extending outwards from the cay for 30-40 yards to living reef; it is littered with blackened uprooted blocks of coral, most of them of small size. The seaward shore itself is formed by a steep shingle ridge, which rises northeastwards to a maximum height of 5-6 feet above sea-level (fig. 44). It is formed of white to grey coral rubble, in which *Acropora* sticks and slabs and small *Montastrea* and other globular colonies are abundant. Banked along the seaward side of this ridge is a lower bank of fresh fine debris, much encrusted with *Homotrema*, and containing abundant nodules of *Lithothamnion* up to 6 inches long. Lagoonward of the crest of the main ridge, blackened and decayed rubble extends for 60-70 yards, before giving way to sand and fine debris. Along the foot of the ridge there is an extensive outcrop of beachrock. This begins near the northeast corner of the cay, in the form of several yards of incipient beachrock at about mean sea level; the beachrock here is little more than an indurated crust on fine sand. Following the rock southwestwards, it appears after a short interval as a distinct seaward-dipping ridge of more consolidated rock, forming a platform 1-2 feet wide, with a broken, pitted surface, from which rise several higher fragments 6-9 inches above the general level. These projections appear to be coral colonies weathered out of the general beachrock matrix. The beachrock trends parallel to the reef, and maintains this parallelism when the shore ridge begins to trend away from the reef-edge southwestwards. The total length of this more indurated rock is about 250 yards.

Near the southwest corner of the cay, the seaward shingle ridge becomes lower, and finally is replaced by a gentle sand beach scattered with coarser debris. Beginning at this point, and extending northeastwards in the lee of the shingle ridge, is a zone of swamp and intermittent standing water 200 yards long. In May 1961 there was no connection between the sea and the swamp area, because of the low sand ridge colonised by a stand of mature *Rhizophora* 25-30 feet high. This colony now stands on dry land 2 feet above sea-level round the southwest margins of the swamp area, and by its attitude appears to have been advancing seaward for some time. This evidence of outbuilding appears to conflict with the evidence of shore retreat at this point shown by the beach-rock. In May 1961 the depression enclosed two mudholes with standing water, surrounded by extensive flats at about mean sea level, with rich brown humic soil, probably at one time under mangroves. Lagoonward of this depression rises a broad low sandy mound forming the lagoon shore. Elsewhere the cay surface sinks gradually from the edge of the shingle zone to the lagoon beach.

Sedimentation appears active at both NE and SW ends of the island. At the southwest end a small unvegetated sand-spit has built out 25 yards into the lagoon, and is continued by a broad submerged spit, with several Rhizophora seedlings growing on it. At the northeast corner a hook-like spit has built out westwards into the lagoon, to enclose an extremely sheltered bay, containing a near-stagnant shallow pool of water. There is no evidence of undercutting round the cay margins, except for one or two fallen coconut trees on the northeast shore.

As with the rest of the Glover's Cays, most of the vegetation (fig. 45) has been removed for coconut plantation. At the northeast end of the cay, and along most of the sandy lee side, there is an extensive ground cover of Ambrosia hispida and Stachytarpheta jamaicensis. The shingle area supports a few small bushes of Tournefortia gnaphalodes, whose seedlings have invaded the sand area to the northeast, and more extensive carpets of Hymenocallis littoralis, scattered bushes of Conocarpus erectus, and coconuts. Large red mangroves (Rhizophora) and Conocarpus are found round the mudholes, especially on the seaward side, but most of the vegetation round the island margins has been cleared. The lagoon beaches are colonised only by low grasses, Stachytarpheta and similar plants in places, and occasional Conocarpus bushes. The greater part of the island is covered with coconuts, with little ground cover. The bottom of the northern bay is thickly covered with Thalassia.

There are several huts on the cay, which is generally inhabited, and a single poor quality well.

Southwest Cay I

Southwest Cays are situated near the southwest extremity of the southeast reef of Glover's Reef, and are the most southerly cays on this atoll. There are two islands in the group (Admiralty charts dubiously mark a third small one to the north of the two large islands); and these are here termed, for convenience, Southwest Cay I (the northeast cay) and II (the southwest cay, Salvin's "Southwest-of-all Cay"). To some extent these two cays form a unit, but as they have very diverse characteristics they will be separately described.

Southwest Cay I (fig. 46) is located 2½ miles southwest of Middle Cay. It fronts a shallow reef-flat, 60-70 yards wide, studded with blackened coral blocks, much pitted and eroded, and is aligned with its long axis parallel to the reef. The island is trapezoidal in shape: it has a maximum length of almost exactly 500 yards, and decreases in width fairly regularly from 330 yards along its southwest shore to little more than 100 yards along its northeast side. The same physiographic units are present on the island as on the other Glover's Reef cays, but their degree of development differs and their pattern is more complex. Essentially the cay falls into three parts: a seaward rubble and shingle area, an interior swamp zone, and the leeward sand area. The seaward shingle and rubble zone does not form a continuous distinct ridge, as on the other cays. It consists of large, deeply weathered, jagged blocks of coral, forming a low rubble carpet, gradually becoming

sparser seawards and more continuous landwards. Many of the blocks are no longer identifiable on casual inspection; there are hardly any fresh blocks, and most of those exposed are coloured yellow, grey or black, presumably by surface algae. Near the seaward edge of the rubble zone, the blocks stand in water 3-4 inches deep, and the floor here consists of pitted, eroded yellow and grey rock. The width of the reef-flat and shallowness of the water make it likely that considerable variation in temperature, salinity and pH take place near the shore. A number of marine molluscs are very noticeable in and around the blocks. The rubble zone over the greater part of its extent (i.e. for some 300 yards from the northern end of the cay) does not rise more than two feet above the sea: the blocks simply become more crowded landward, and are covered with dense vegetation, through which one catches glimpses, from the seaward shore, of the interior swamps. Toward the middle of the seaward side of the cay, however, a number of large Avicennia trees have advanced across the rubble zone almost onto the reef-flat, and southwest of this point, the seaward shore changes in character. The amount of rubble in front of the shore decreases, the shore itself steepens, and is formed by an arcuate shingle ridge 5 feet high, overlooking a small sand beach containing much Halimeda. This true shingle ridge is about 150 yards long; it consists of white to grey small coral shingle, similar to that on the other cays. From the crest of this ridge the cay surface declines rapidly at first, then more gently, to the leeward shore.

The seaward shore does not trend parallel to the reef for its whole extent: for the greater part it does, and is here fringed either by the rubble zone or shingle ridge, but towards the southwest the shore turns westwards, while the reef continues along its NE-SW axis. As the shore swings away from the reef, the reef-flat widens and deepens, the fringe of blackened boulders disappears, and the shingle ridge gives way to a narrow sand beach.

From this account and the map, it is apparent that the seaward shore is backed by a zone of swamp and standing water, divided into two parts. The first extends from the northeast side of the cay, in the lee of the rubble zone, and is some 280 yards long and up to 120 yards wide. The second extends inland from the southwest side of the island for distances of 120-180 yards. It is interesting to note that the marsh zone is interrupted immediately in the lee of the true shingle ridge, where dry land extends across the whole width of the cay, but it is impossible to state with certainty whether this is due to sedimentation and drying out of the mudhole at this point, or to higher upbuilding of the original cay surface. The two swampy areas are rather different in character. The larger one includes a number of pools of standing water, but the natural vegetation has been cleared, and an effort is being made to colonise almost the whole of this low-lying area with coconut palms. These are planted out in rows as young seedlings, several yards apart, and banked up with fresh sand from other parts of the cay. There are several dozen of these conical mounds of sand, each with a young coconut palm, often rising out of shallow stagnant water. Along the seaward margin of this larger swamp, and along the northeast shore, are a number of Rhizophora and Conocarpus trees.

The southwest swamp area is wilder; there is less standing water, but the ground is very soft and muddy. There are many coconut trees in the swampy area, which do not seem to have been planted, while along the southwest shore and in places throughout the swamp are trees of Conocarpus and Rhizophora. From the seaward side the southwest shore presents an unbroken fringe of red mangrove, 10-15 feet high, rising out of water up to 2 feet deep. There is, however, no general connection between the sea and the swamp, for on scrambling through the Rhizophora rim one reaches a low sand ridge some yards back from the seaward edge, forming a barrier between sea and swamp. Isolated clumps of Rhizophora extend reefward from the main body of mangrove, to partially enclose a small bay on the seaward shore; this bay is very sheltered, has a low sandy shore, and is floored with Thalassia and Penicillus.

The area between the two swamp zones, and along the north shore of the cay, is built of grey sand with little relief. Much of the lagoon shore is undercut, and in plan consists of a number of small bays and promontories, the latter often topped with leaning or fallen coconut trees. Near the northeast end of the lagoon beach, a large number of trees have fallen landward, and now lie in a roughly north-south direction, probably indicating storm action. The bottom is generally shallow on the lagoon side, with a Thalassia bottom, and there is much fresh white sand accumulation at the foot of the undercut cliff. At the southwest end of this shore, a small spit is building out into the lagoon, and several weed-covered sand-banks are exposed at low tide.

Much of the vegetation (fig. 47), especially of the sand and swamp areas, has been removed for cocals, and much of what remains is mangrove —Rhizophora mangle on the southwest and northeast shores, Avicennia nitida and Conocarpus erectus along the seaward side, and associations of these three in the swamps themselves. There are a number of Tournefortia gnaphalodes bushes on the high shingle ridge, and a little Tournefortia and Coccoloba uvifera on the drier parts of the rubble zone. The greater part of the sand surface, under the cocals, is covered with Euphorbia, grasses (including Sporobolus virginicus), and coconut trash.

There are four houses on the cay, which is generally inhabited. There are no freshwater wells, and only small tanks for rainwater.

Southwest Cay II

Southwest Cay II (fig. 48) lies immediately south and west of Cay I, but is very different in physiography. Unlike Cay I it is not aligned parallel to the reef-front, but at an angle of some 45° to it, the cay trending slightly east of north and the reef NE-SW. Immediately west of Cay II is the main southern entrance of Glover's Reef. Cay II is rather longer than its neighbour (total length 580 yards), is widest in the south (nearly 250 yards), and decreases in width northwards. The northern half of the cay maintains a fairly constant width of 80-100 yards.

Only at its southern end does the island approach the reef, and thus shingle is absent except on the south and extreme southeast shores. Nor is the swamp zone found on every other large cay on Glover's Reef represented here. The cay is built mainly of white to grey sand, with much Halimeda and small unrecognisable coral fragments, with an admixture of larger pieces of broken coral, Strombus shells, nodular calcareous algae and other calcareous material, giving a strongly bimodal sediment distribution. The shingle ridge at the southeast end does not rise higher than 3-5 feet above sea-level, and consists of small coral fragments, mostly less than 6-9 inches long. The ridge overlooks a reef-flat 25-30 yards wide, littered with blackened blocks and coral rubble. The rest of the cay margins are built of sand, which rather anomalously forms a higher ridge on the leeward side than on the windward. The windward beach is generally low, and shallow offshore, with in places a number of Rhizophora seedlings colonising within 5-10 yards of tide mark. The leeward shore is also sandy, but narrow and steep; and the floor of the northern bay falls rather steeply to depths of 4-5 feet. In part this difference is due to more severe undercutting on the north shore, but it probably results to some extent from greater exposure of the lagoon shore. The seaward shore lies from 100-250 yards from the reef-edge, the only source of abundant coarse and sand-size debris. Further, the flat is shallow, so that only in times of exceptional wave activity will material from the distant reef be thrown up on the seaward shore. The lagoonward shore, trending slightly east of north, is protected, it is true, from the prevailing easterlies and northeasterlies, but is exposed both to northers sweeping down the deep lagoon, and to large waves refracting through the southern entrance.

The undercutting referred to affects much of the cay margins--along the lagoon shore, and along the central part of the seaward shore. On the lagoon shore, undercutting extends for 280 yards from the north end of the cay, and has produced a low, grey-sand cliff between 1 and 2 feet high, capped by vegetation and roots, and overlooking a very narrow white-sand beach. In plan the shore forms a series of minor embayments, with coconut boles on the promontories. Many trees have fallen into the sea; others lean at perilous angles. Further evidence of recent retreat on this coast is found in relict beachrock offshore. There are three separate areas of this, comprising respectively from south to north, two lines, one line and four lines of rock. The rock itself is a well-cemented coarse sand, now rather eroded and pitted on its upper surface and cavernous beneath. All the exposures show in some part a recognisable dip lagoonward. Each of the lines trends nearly north-south, some a little west of north; the coast itself trends almost NNE, and is clearly retreating eastwards. The amount of this retreat seems, from the extent of beachrock in each place, and its distance from the present shore, to increase northwards, and in fact, south of the southernmost beachrock outcrop there is no evidence of coast erosion at all on this side of the island. This pattern probably results from the refraction of waves round the south end of the island, through the southern entrance. Along the southern part of the lagoonward shore the waves are further refracted and advance transverse to it: in the south the shore is static or even aggrading, in the north it is retreating, and the degree of retreat increases northwards.

The southern part of this lagoon shore is of interest. Immediately south of the undercut zone, the shore is formed by a beach of hard-packed white sand, some 20 yards wide, and rising 2-3 feet above sea-level. Vegetation begins at the crest of this beach, though a few bushes of Conocarpus in places occur below it. At the extreme southwest corner of the cay, aggradation is now active. The line of the "core-island" can be traced as an undercut low cliff of grey sand, capped with coconuts, and partially obscured below by fresh sand accumulation. This fresh sand extends lagoonward for 20-30 yards from the old shore, and is thrown up in three main ridges, approximately equidistant, with a fourth much smaller ridge very recently built round the present shore. That this whole accumulation is not seasonal is demonstrated by the vegetation. On the "core-island" above the cliff, there is little but coconuts and some lilies. The succeeding depression is either bare or has a sparse cover of Sporobolus virginicus, but on the first sand ridge from the cliff there are a number of young coconuts, probably less than 5 years old. The backslope of the second ridge is covered with typical strand pioneer colonisers, forming a low mat, chiefly of Ipomoea, Sesuvium and Euphorbia, with occasional Conocarpus. The third and most seaward of the ridges is yet unvegetated. Thus the long-term erosion farther north is balanced by aggradation in the south, extending back over several years at least. Between this zone of aggradation and the windward shingle ridge is a further short extent of undercut shoreline, with a bay-promontory plan, cliffs 1-2 feet high, and some fallen coconut trees.

The seaward shore possesses many points of interest too, but is more enigmatic. North of the shingle ridge (where there is no sign of either erosion or aggradation), the shore is retreating for a distance of 200 yards, as shown by undercut and outstanding coconut boles. But the erosion is not so rapid as that on the west side; the offshore area is gentle and colonised by many mangrove seedlings. Erosion is clearly caused by waves traversing the wide reef-flat almost normally. Beachrock is exposed on this side of the cay also, along the present shoreline. There are several patches of poorly to moderately well-cemented sand with Halimeda, the longest extending for 15 yards. There is only one line of the rock, about 2 feet wide, passing under beach sands, not eroded on its surface (which is covered with a rather slimy grey coating), and dipping lagoonward. This is the only example of beachrock with reversed dip on a seaward shore noted on this coast; though examples in other parts of the world are numerous. The reverse dip of exposed surfaces was confirmed by pit-digging 1 and 2 yards up the beach, when the rock was found in both pits at slightly lower elevations than its seaward exposure. If the beachrock now stands in its position and attitude of formation, then it seems that the whole cay has migrated bodily at least 100 yards away from the reef-edge and towards the lagoon since it was formed, in spite of the relatively clear evidence of present erosion on the west, lagoonward shore. In this case the unweathered appearance of the rock is explained by its protection beneath the cay sands. Alternatively, the islandward dip may result from some at present unexplained anomaly, and may have formed recently along the present seaward shore.

Farther north, the evidence of erosion is less, and the shore is margined by a belt of tall Rhizophora 2-3 yards from it, and comparable to the similar belt on the southwest shore of Cay I across the bay. Between the Rhizophora belt and the north end of the island the shore is low and sandy, with very numerous brown sea anemones in shallow water offshore, and some surface induration of sands on the beach itself, presumably almost contemporaneous in age and too friable to collect. The sheltered state of this site might be noted. At the north end of the cay, where it approaches closest to Cay I, a narrow sand-spit some 40 yards long, exposed at low tide, is developing, growing outwards towards a similar spit at the southwest end of Cay I.

The natural vegetation of the cay has been very largely removed for cocals, which now cover almost all the island. One or two Conocarpus bushes are found around the cay margins, especially at the north end, but otherwise vegetation is restricted to a ground cover of climbing plants and grasses, chiefly Sesuvium portulacastrum, Euphorbia sp., Ipomoea sp., and Cakile lanceolata. Sporobolus virginicus is widespread, with much Andropogon glomeratus at the northern end. Towards the southwest end of the cay, the cocal has an undercarpet of the lily, Hymenocallis littoralis.

The colony of brown noddies (Anoüs stolidus) on the island has already been mentioned; the number of these birds contrasts sharply with the relatively birdless appearance of most other sand-cays. Pelicanus occidentalis and Fregata magnificens were seen here in July 1961. There are two houses on the cay, for cocal caretakers, and a tank rainwater supply.

It is interesting to speculate on the relations between Cays I and II, and their very different appearance. They have certainly existed in their present form for at least 2 centuries (cf. Owen, H57, 1830). The wide, sand-floored bay on the seaward side, between the two islands, is generally placid, and probably not more than 3 feet deep in any part. The channel between the two cays is kept open by tidal currents, which will probably prevent the two spits, now advancing toward each other from the southwest end of I and the northeast end of II, from meeting. A lobate sand delta, shown on air photographs, has developed on the lagoonward side of the gap between the cays, and will build further lagoonward as more material is supplied from the reef-flat. Whether the two cays were ever connected is a difficult question; Cay I in particular looks like a cay in the process of growth and consolidation rather than a remnant of a larger island. On the other hand, If Cay II formerly stood 100 yards further seaward, as perhaps indicated by the lagoonward-dipping beachrock of its seaward shore, then the two cays would be appreciably closer together, and the bay much smaller. It is difficult to envisage a bay of this size being eroded under present conditions. One may expect a progressive attenuation of the northern part of Cay II, by erosion on the lagoon side, which may ultimately widen the gap between the two cays, while at the same time the southern part of II increases in size. The consolidation of Cay I, much of which is--or was--standing water, will be largely the result of human activities.

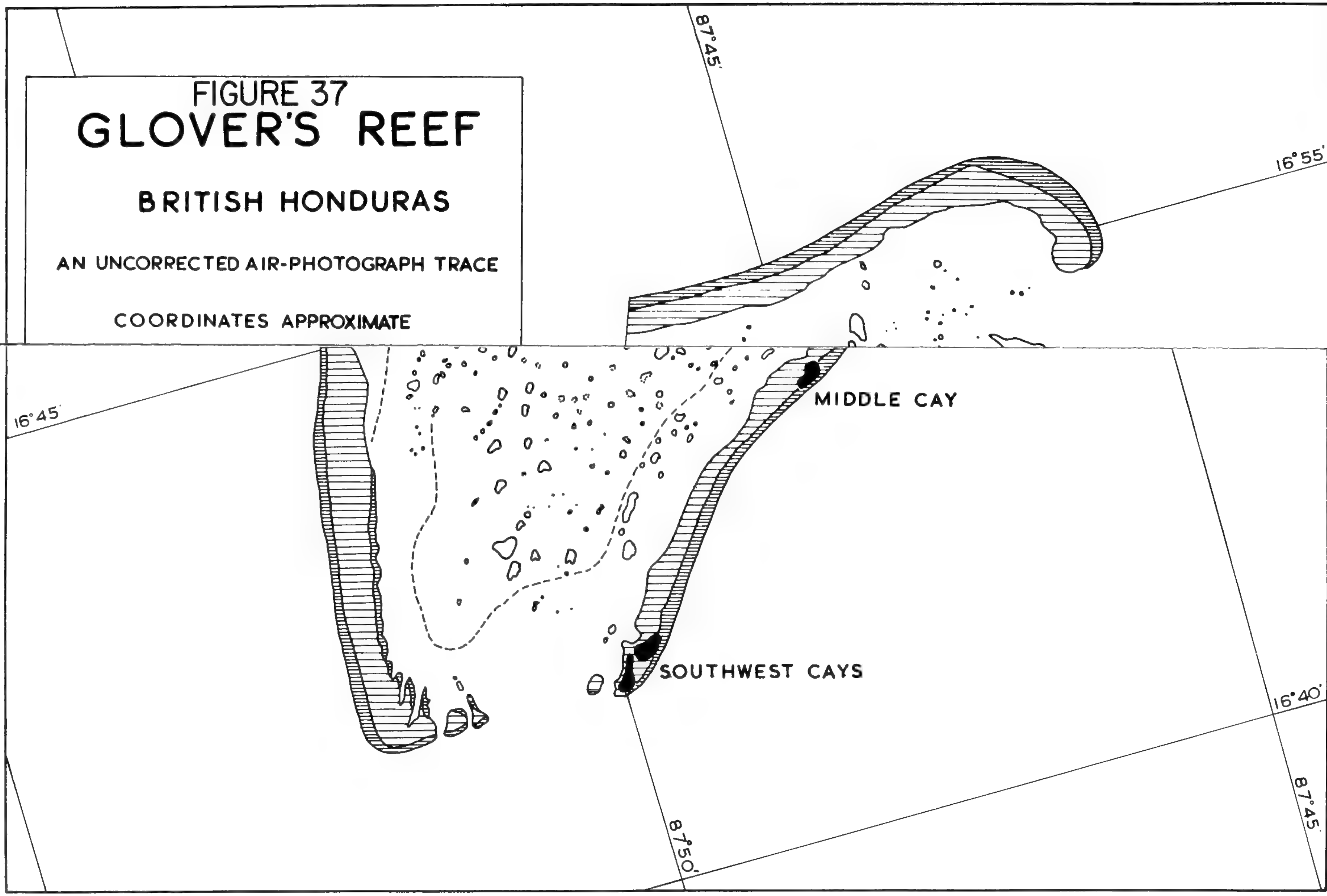


FIGURE 37
GLOVER'S REEF

BRITISH HONDURAS

AN UNCORRECTED AIR-PHOTOGRAPH TRACE

COORDINATES APPROXIMATE

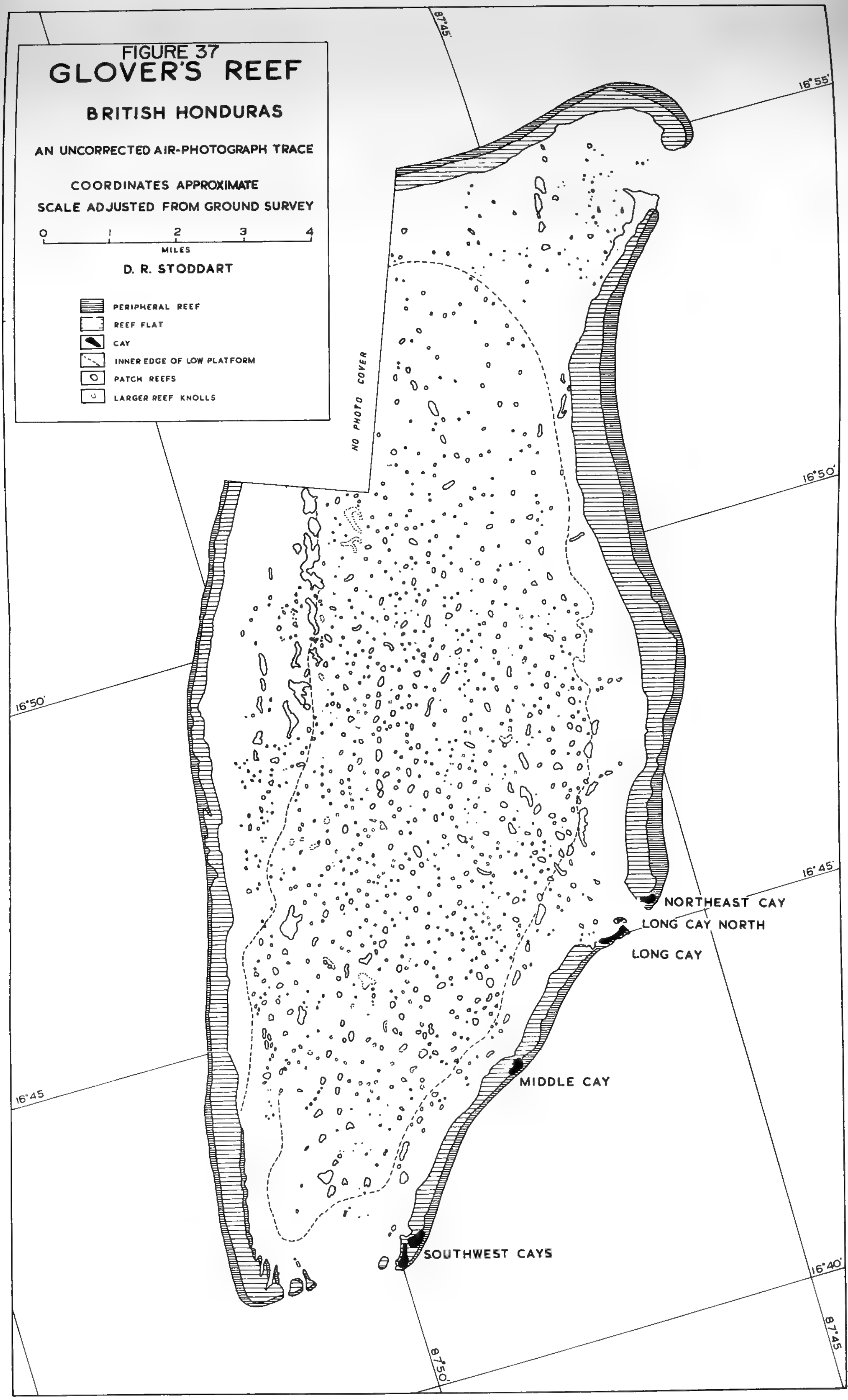


FIGURE 37
GLOVER'S REEF
BRITISH HONDURAS
AN UNCORRECTED AIR-PHOTOGRAPH TRACE
COORDINATES APPROXIMATE
SCALE ADJUSTED FROM GROUND SURVEY
0 1 2 3 4
MILES
D. R. STODDART
PERIPHERAL REEF
REEF FLAT
CAY
INNER EDGE OF LOW PLATFORM
PATCH REEFS
LARGER REEF KNOLLS
NO PHOTO COVER
87°45'
16°55'
16°50'
16°45'
16°40'
87°50'
NORTHEAST CAY
LONG CAY NORTH
LONG CAY
MIDDLE CAY
SOUTHWEST CAYS

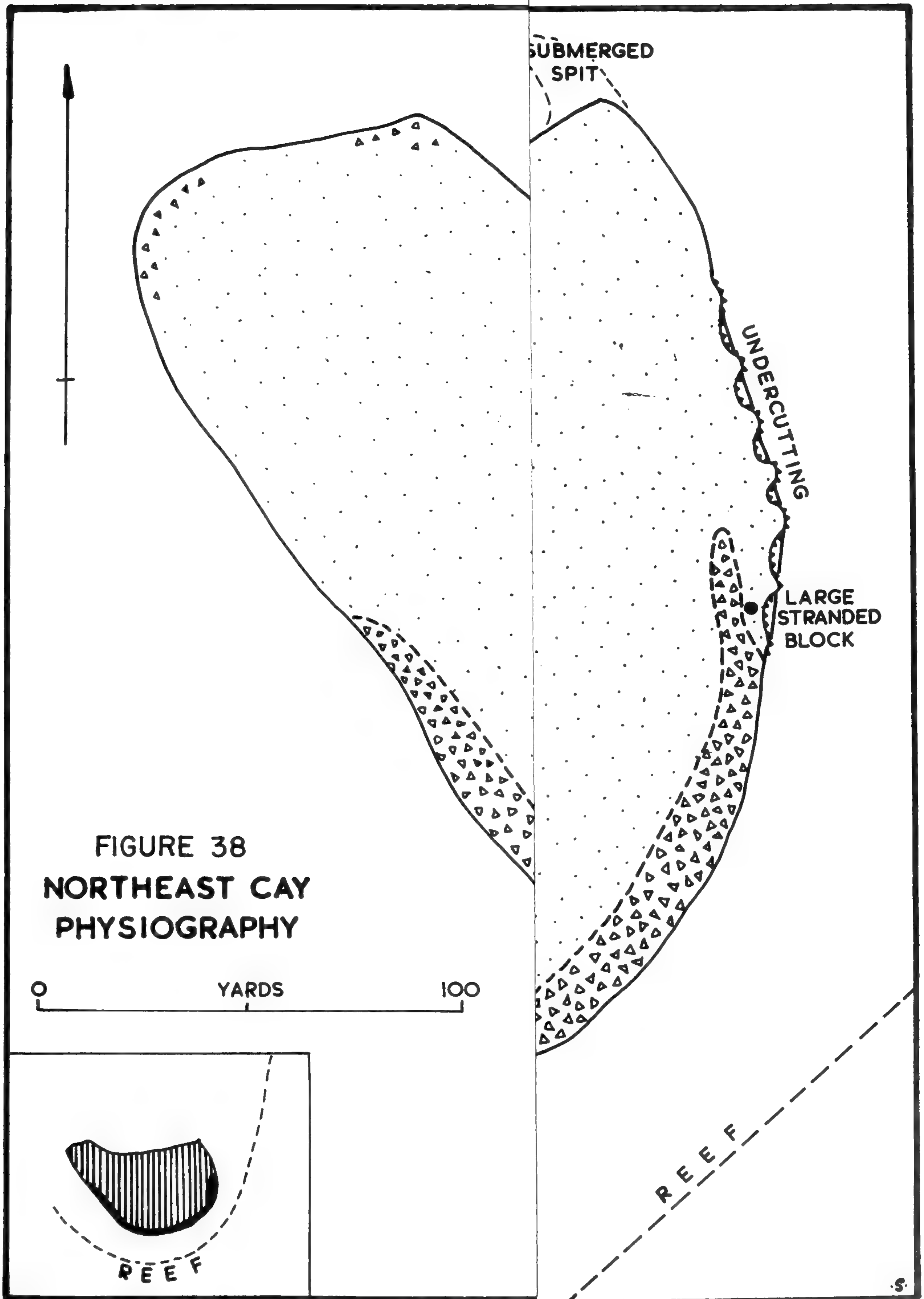


FIGURE 38
NORTHEAST CAY
PHYSIOGRAPHY

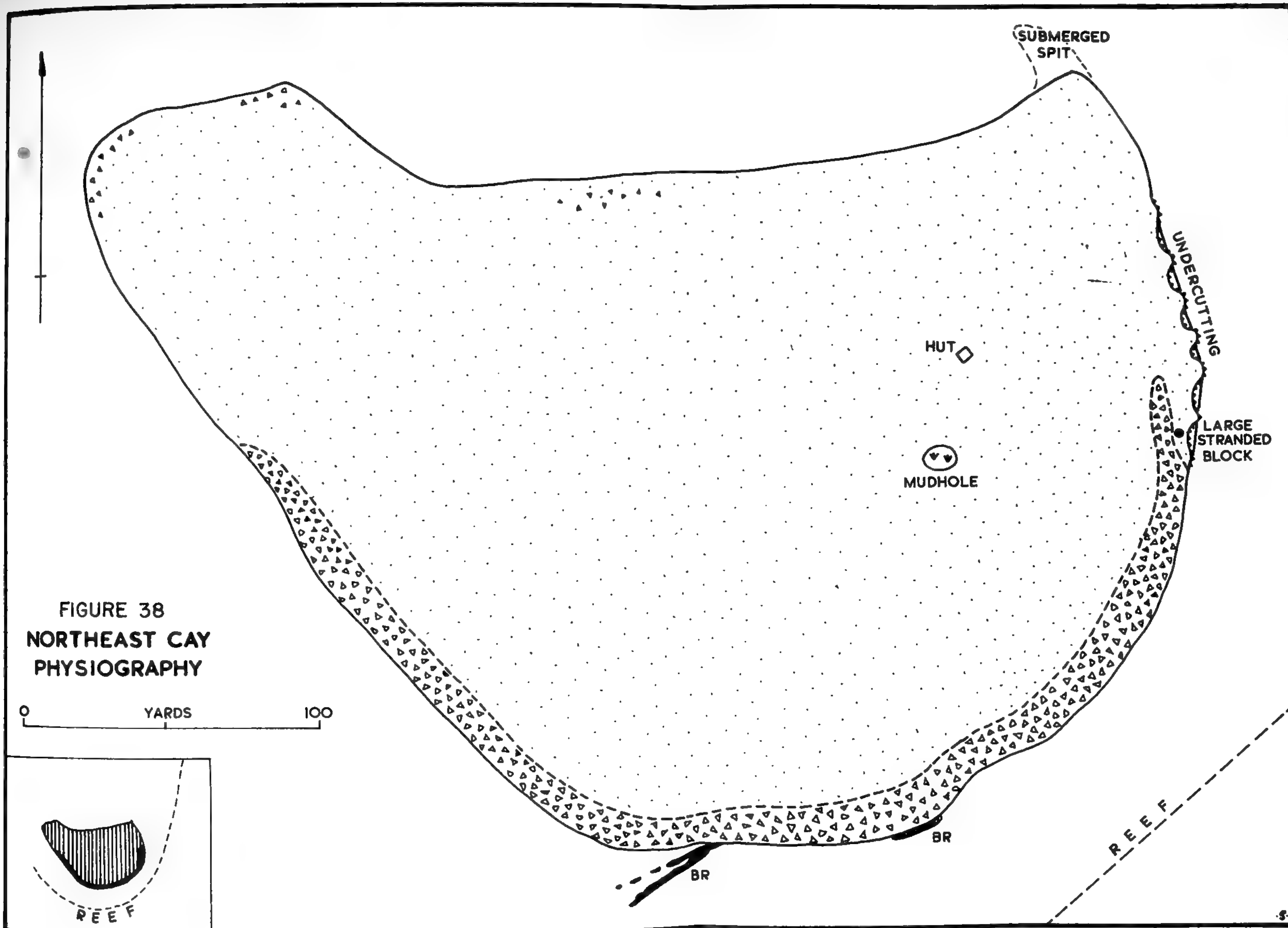


FIGURE 38
NORTHEAST CAY
PHYSIOGRAPHY

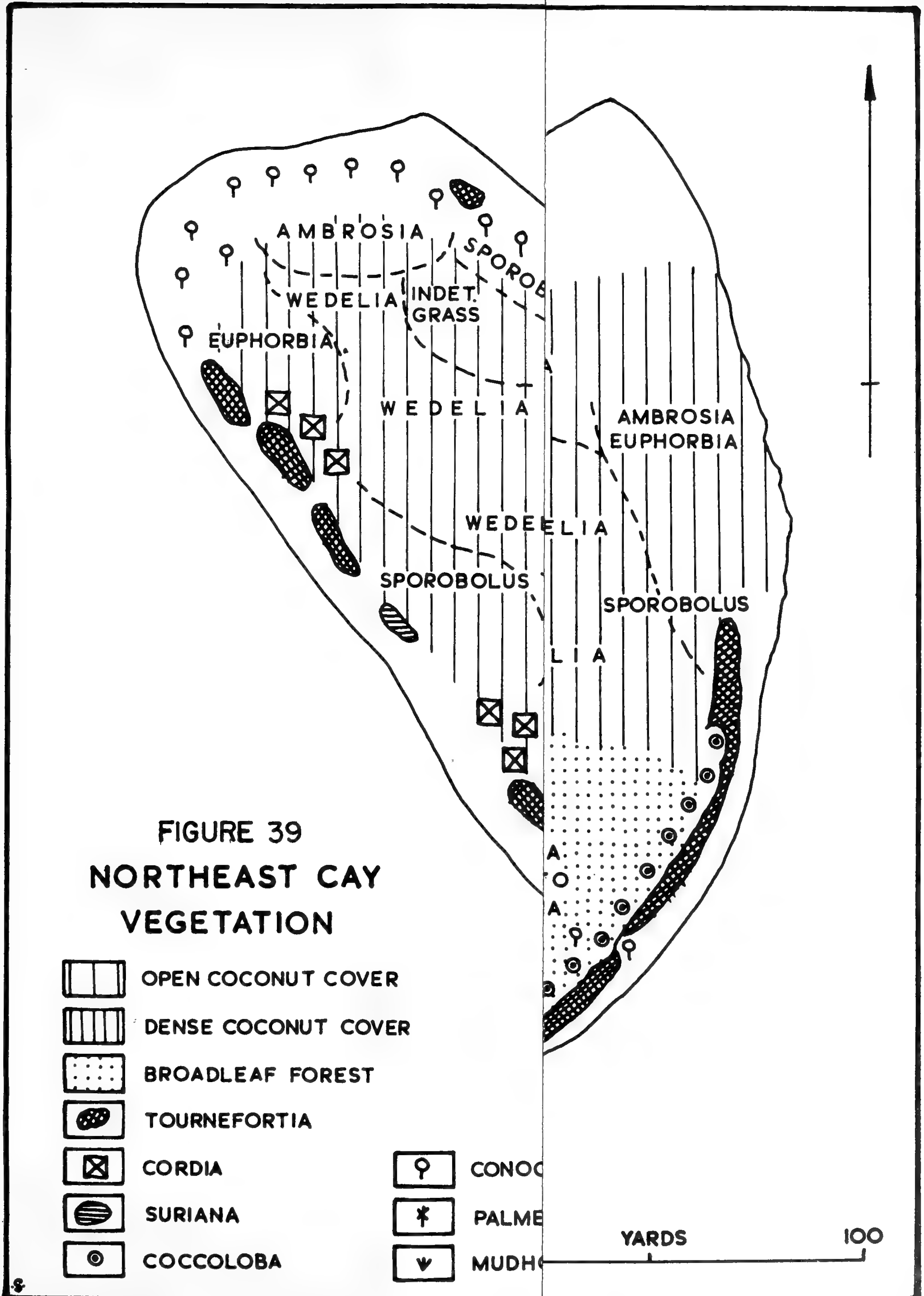


FIGURE 39
NORTHEAST CAY VEGETATION

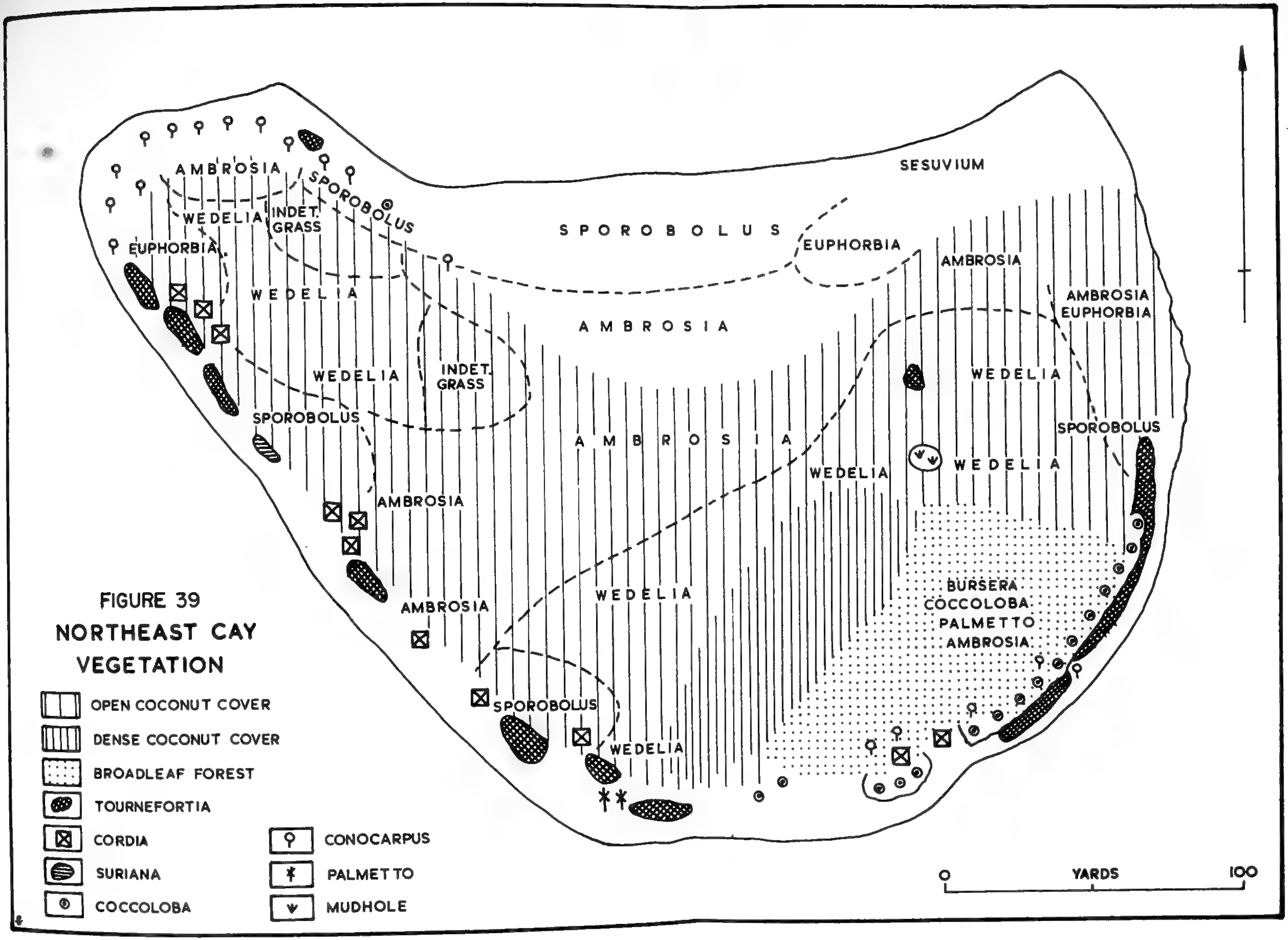
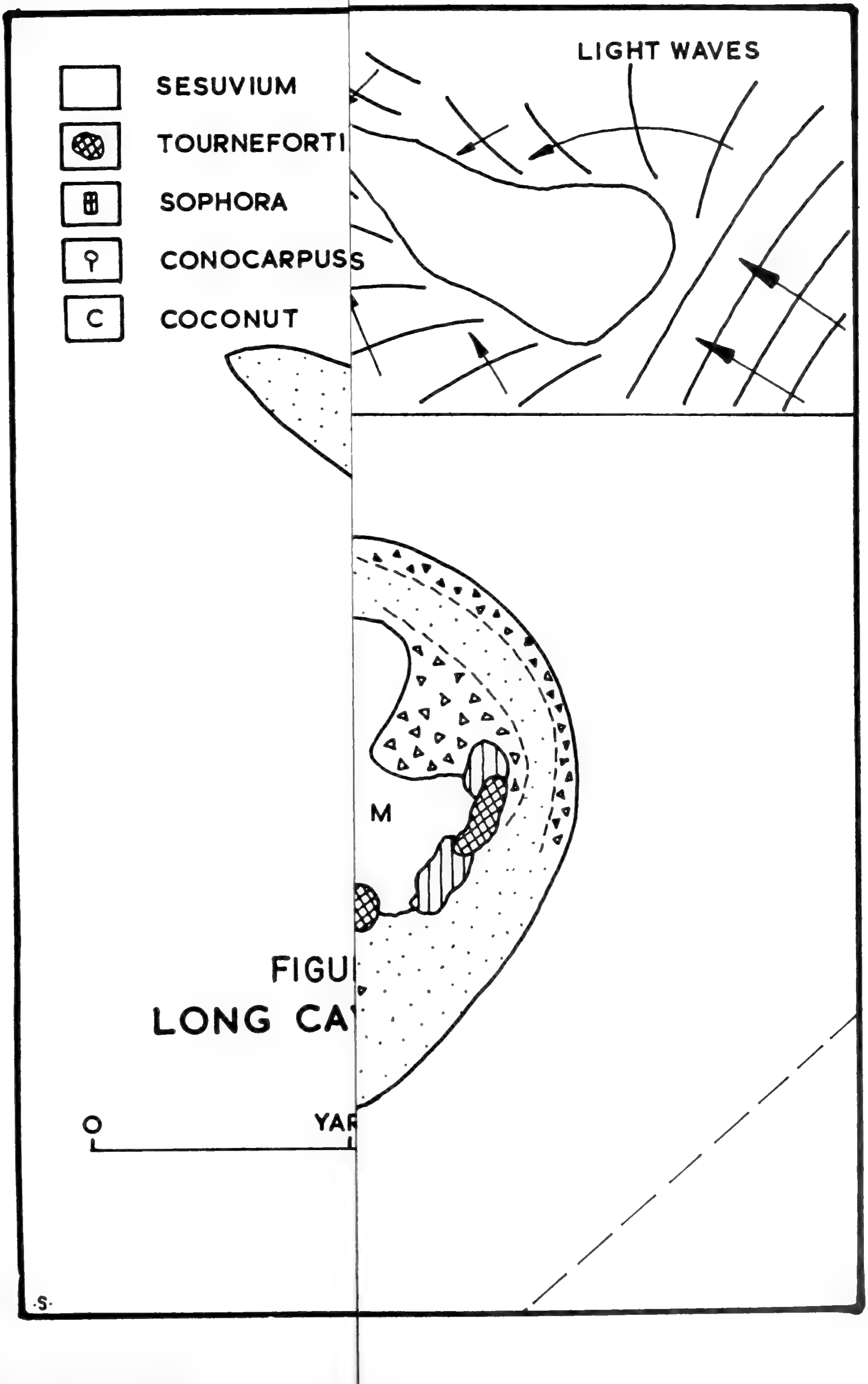


FIGURE 39
NORTHEAST CAY VEGETATION


SESUVIUM
TOURNEFORTI
SOPHORA
CONOCARPUSS
COCONUT
LIGHT WAVES
M
O
YAR
S
FIGU
LONG CA

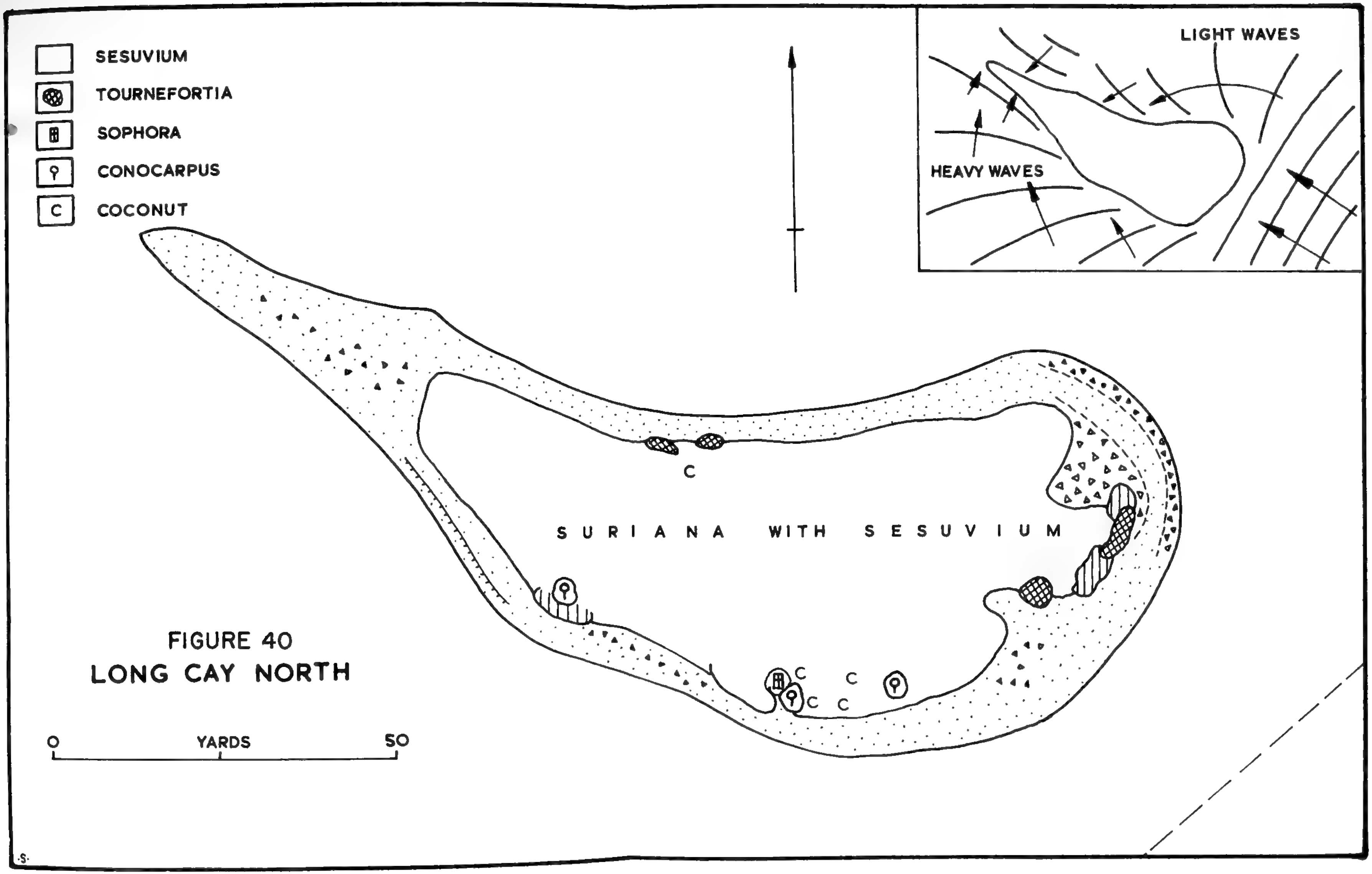


FIGURE 40
LONG CAY NORTH

FIGURE 4

LONG C

GLOVER'S RE

PHYSIOGRAP

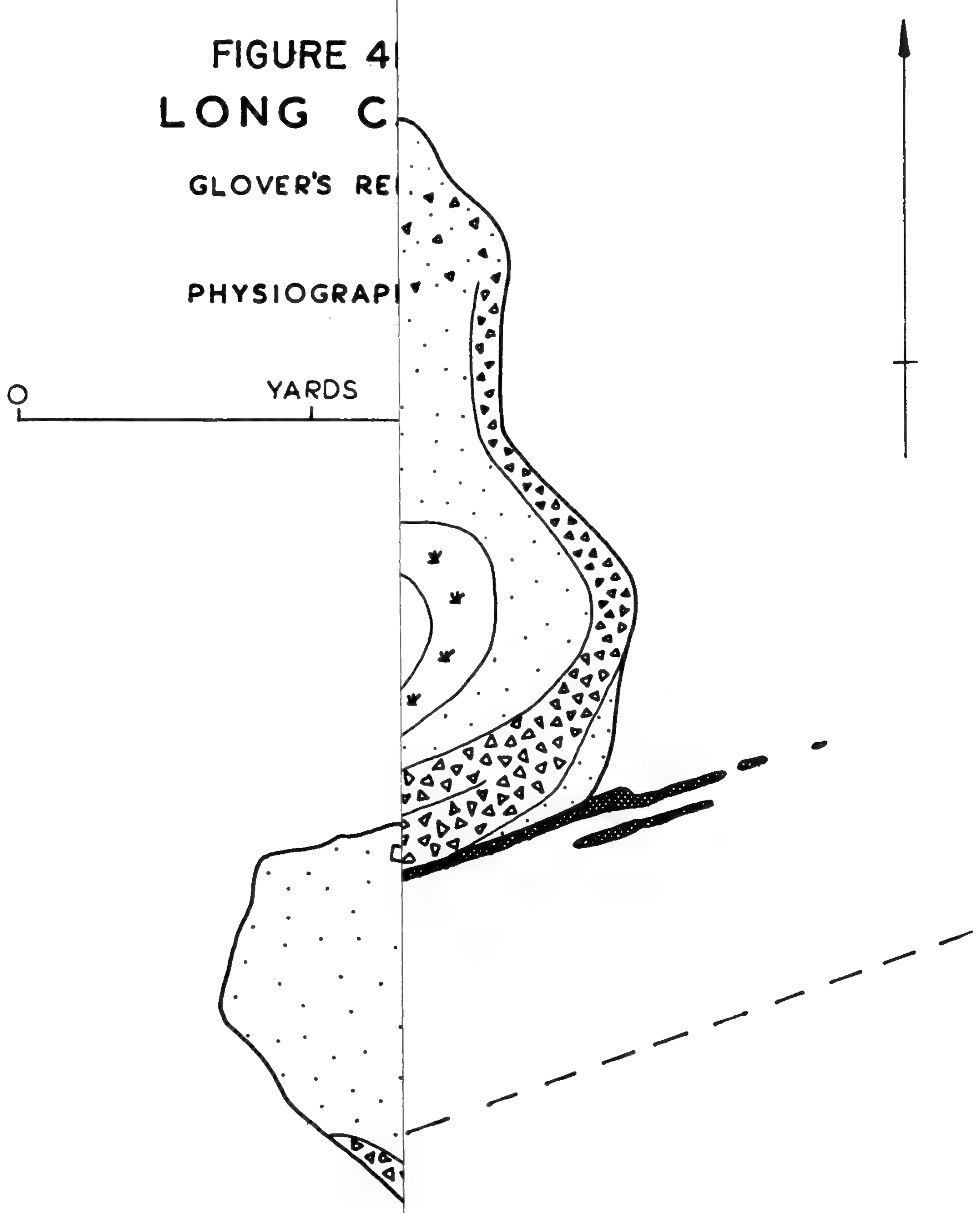
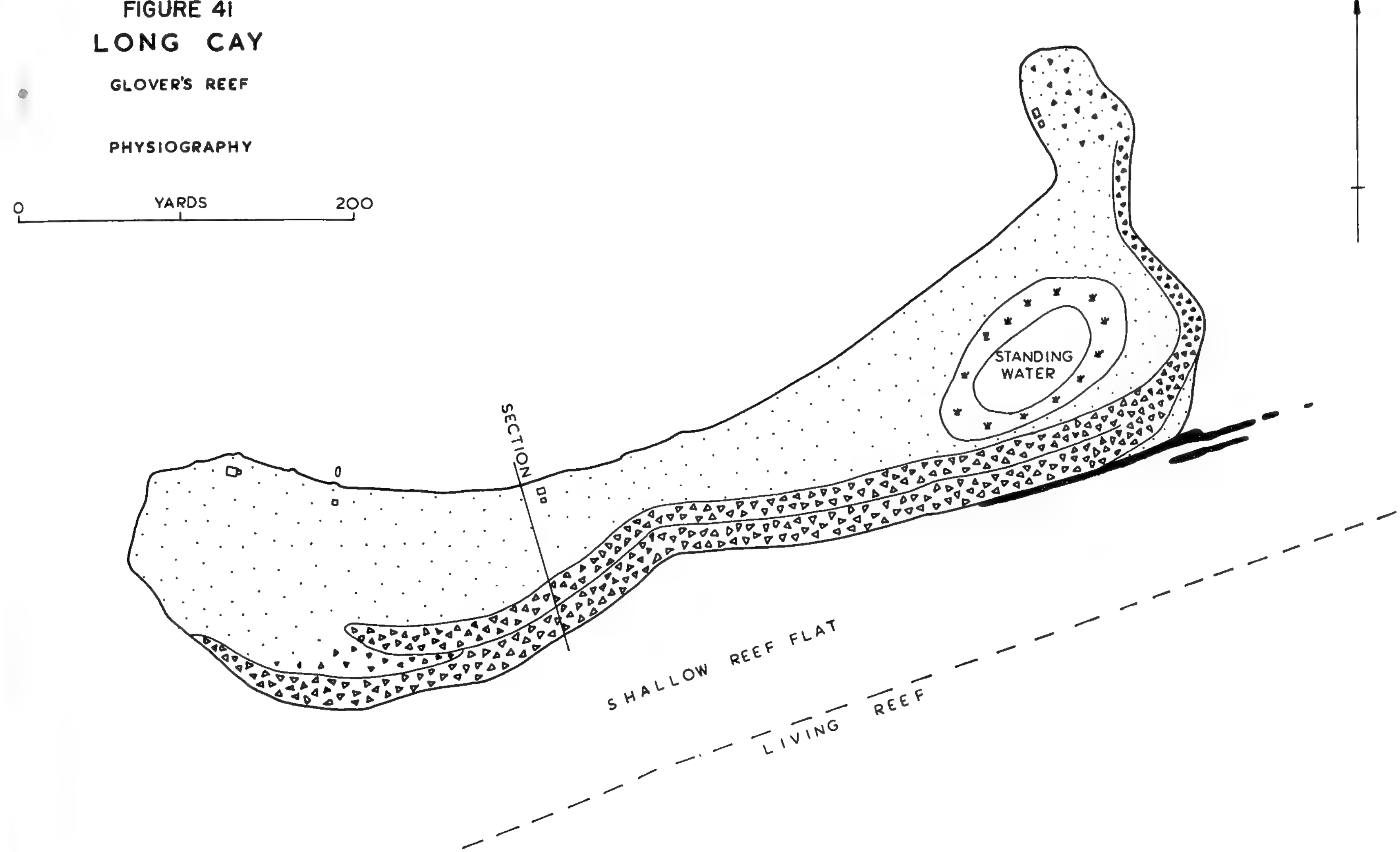


FIGURE 41
LONG CAY
GLOVER'S REEF

PHYSIOGRAPHY



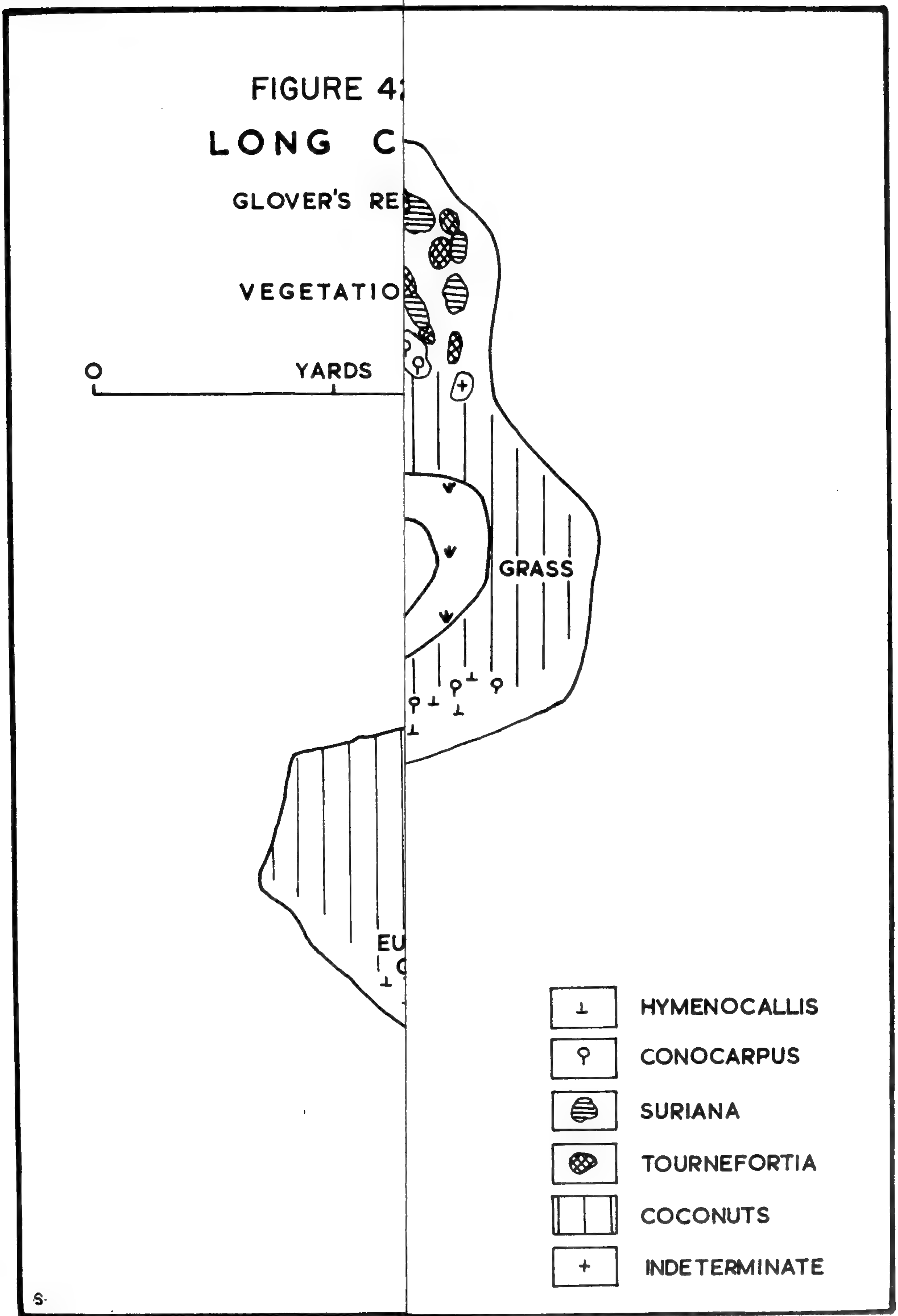


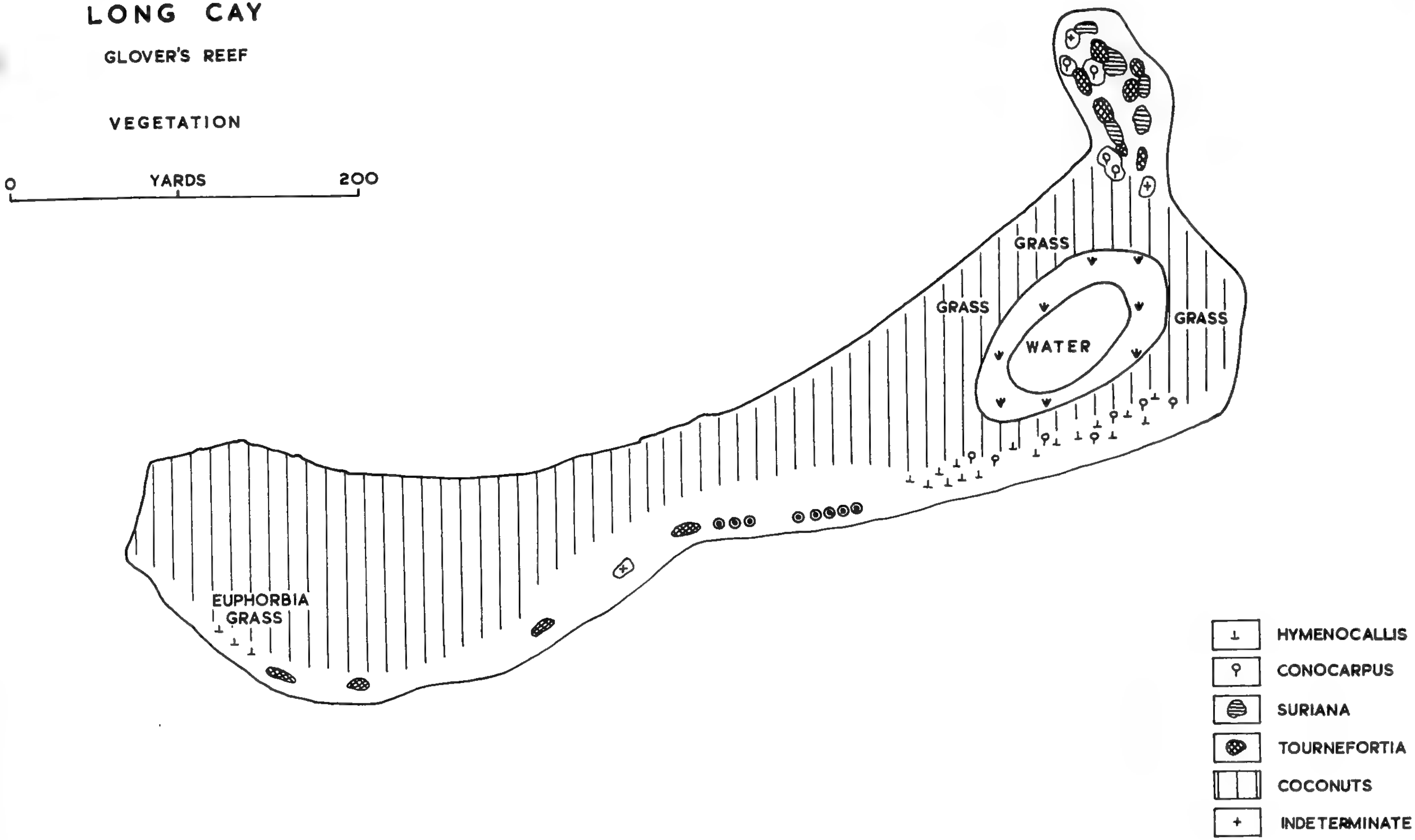
FIGURE 4
LONG C
GLOVER'S RE
VEGETATIO
O
YARDS
GRASS
EU
HYMENOCALLIS
CONOCARPUS
SURIANA
TOURNEFORTIA
COCONUTS
INDETERMINATE

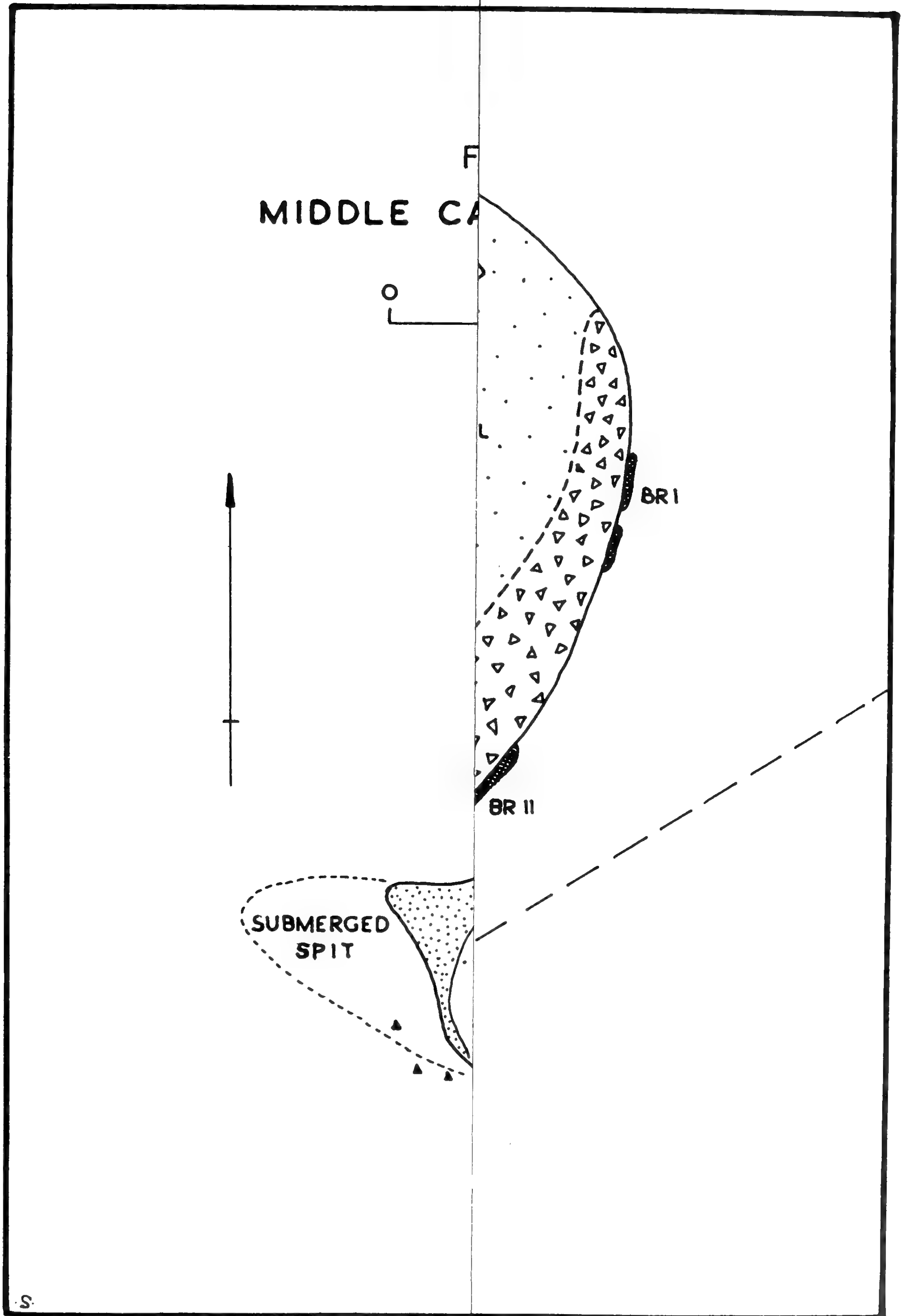
FIGURE 42

LONG CAY

GLOVER'S REEF

VEGETATION




F
MIDDLE CA
O
L
BR1
BR11
SUBMERGED
SPIT

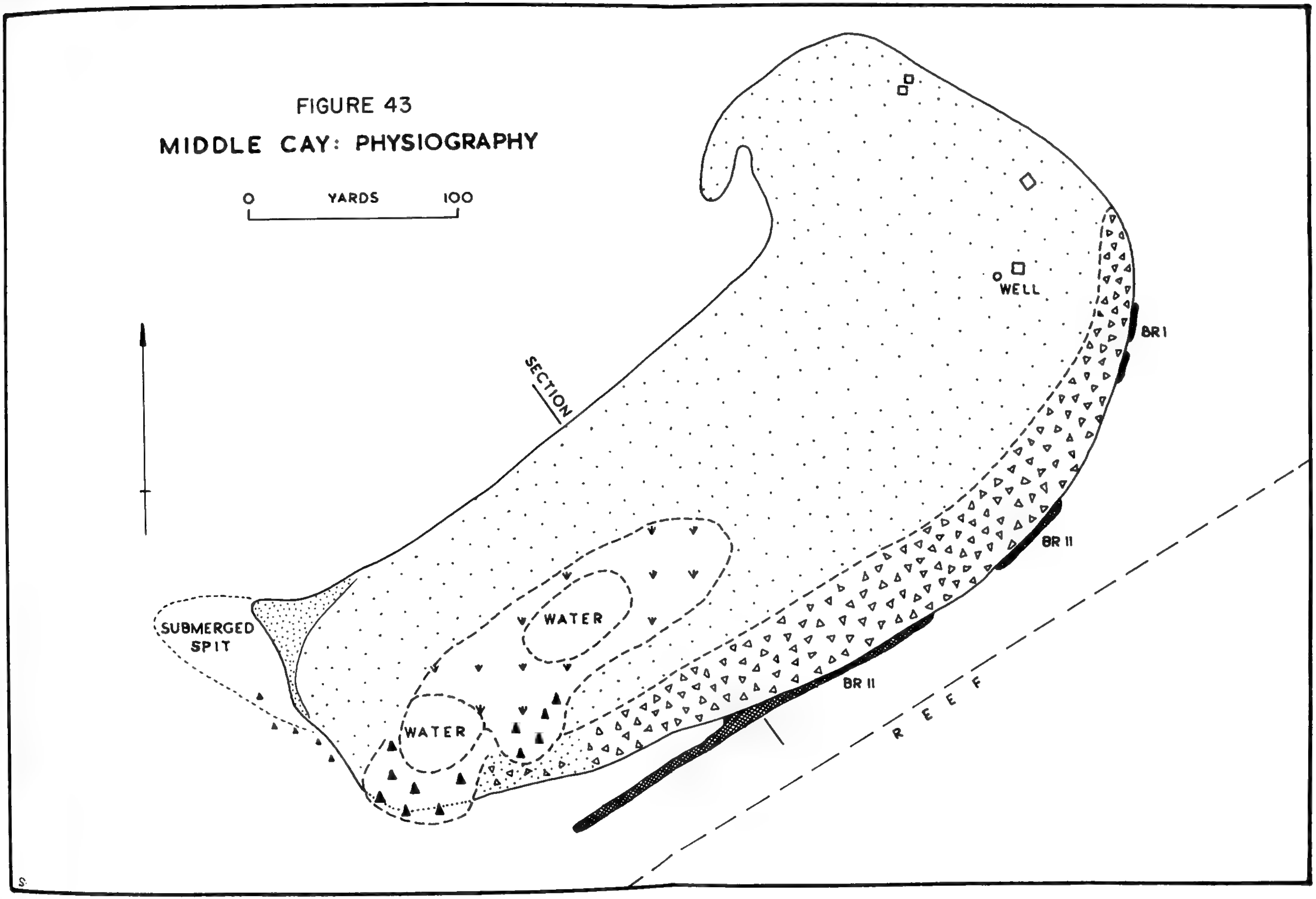


FIGURE 43
MIDDLE CAY: PHYSIOGRAPHY
0 YARDS 100
SECTION
WELL
BR I
BR II
BR II
WATER
WATER
SUBMERGED SPIT
REEF
S.

FIGURE 44
LONG CAY

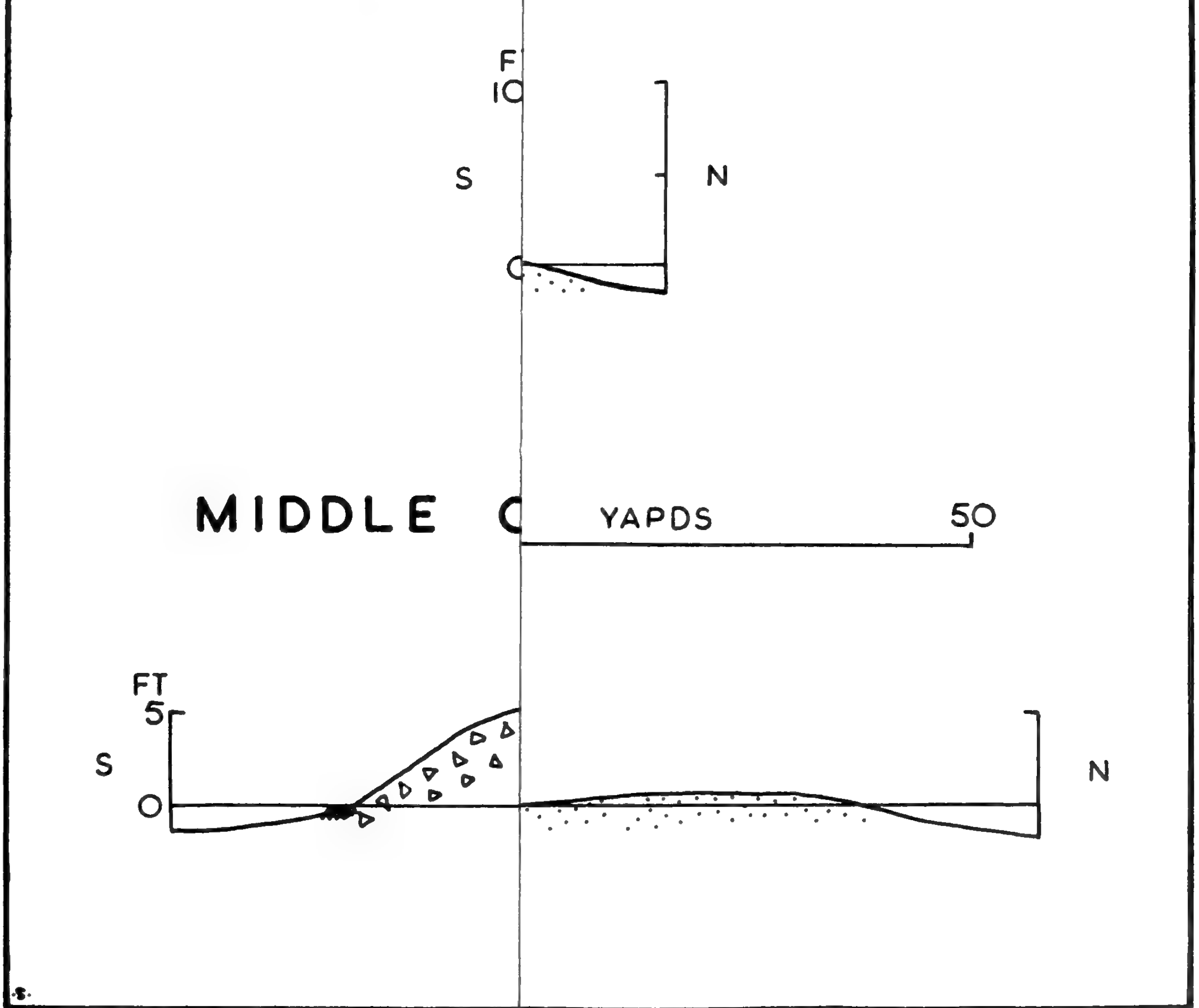


FIGURE 44
LONG CAY

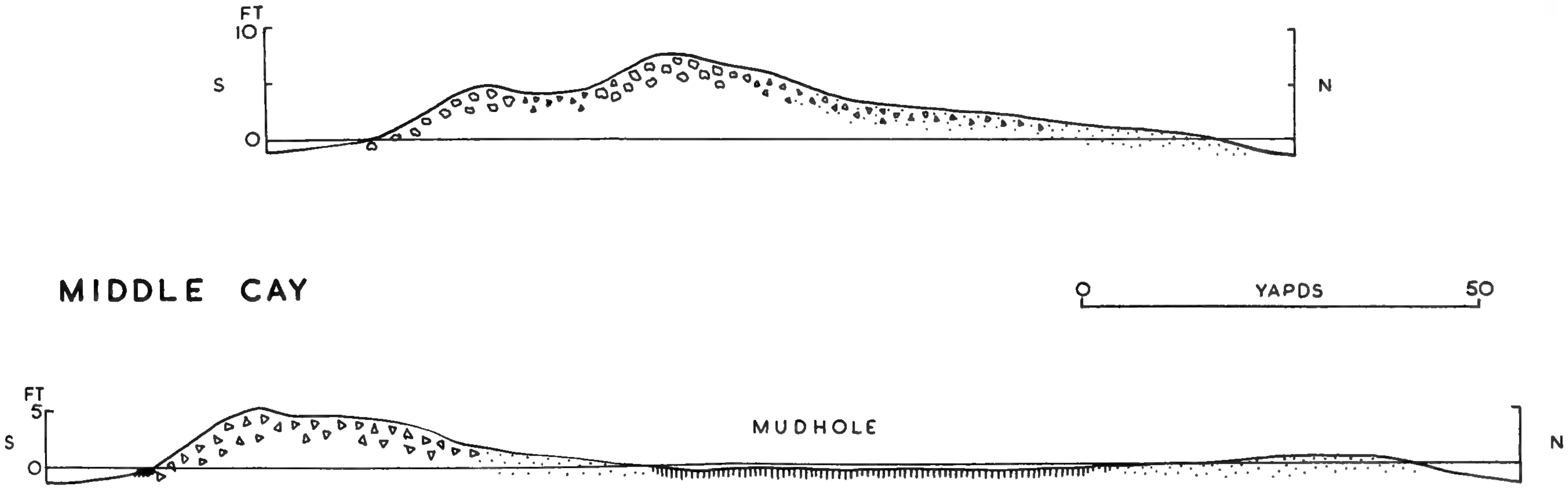


FIGURE 4

MIDDLE CAY: VE

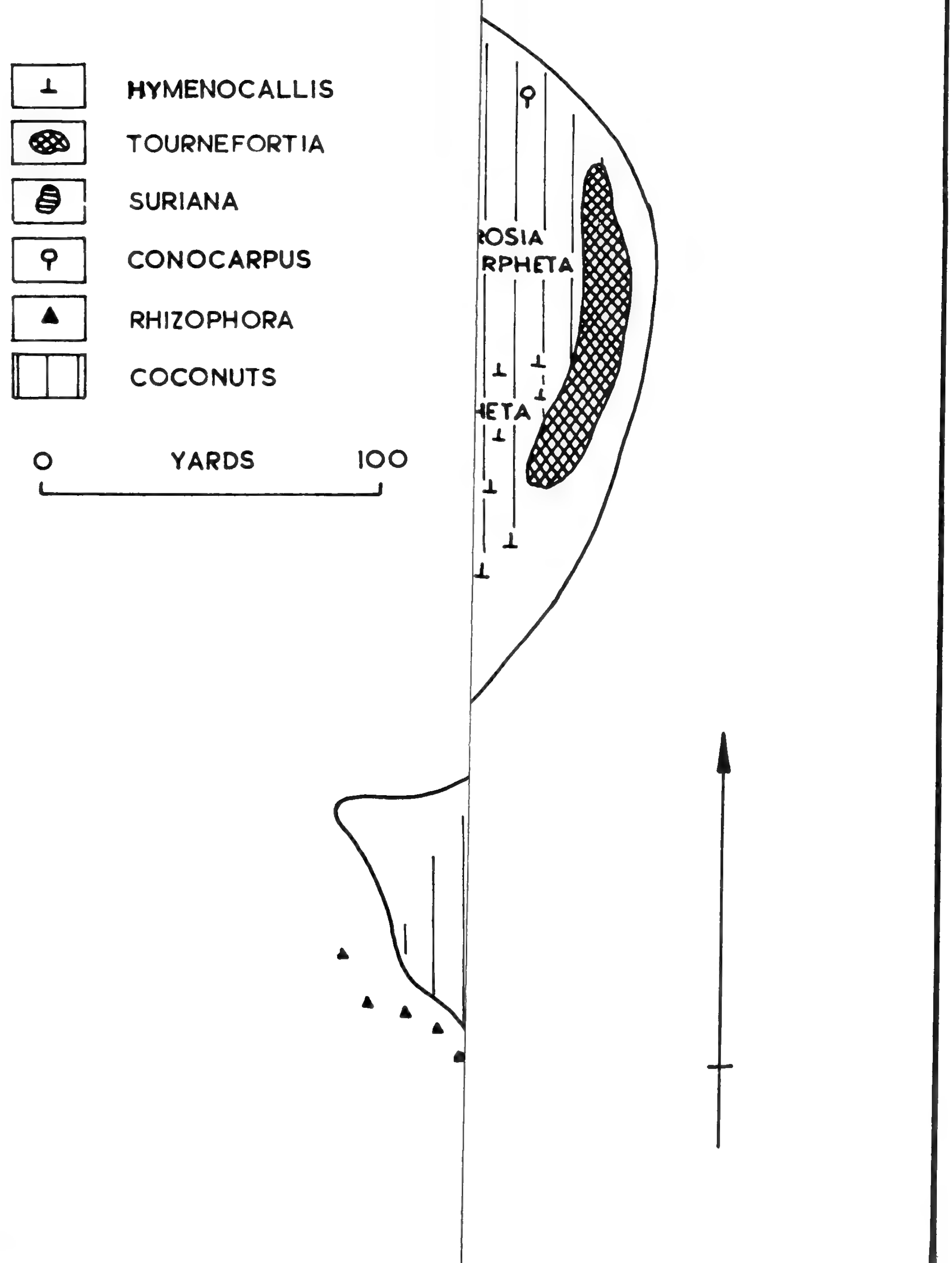
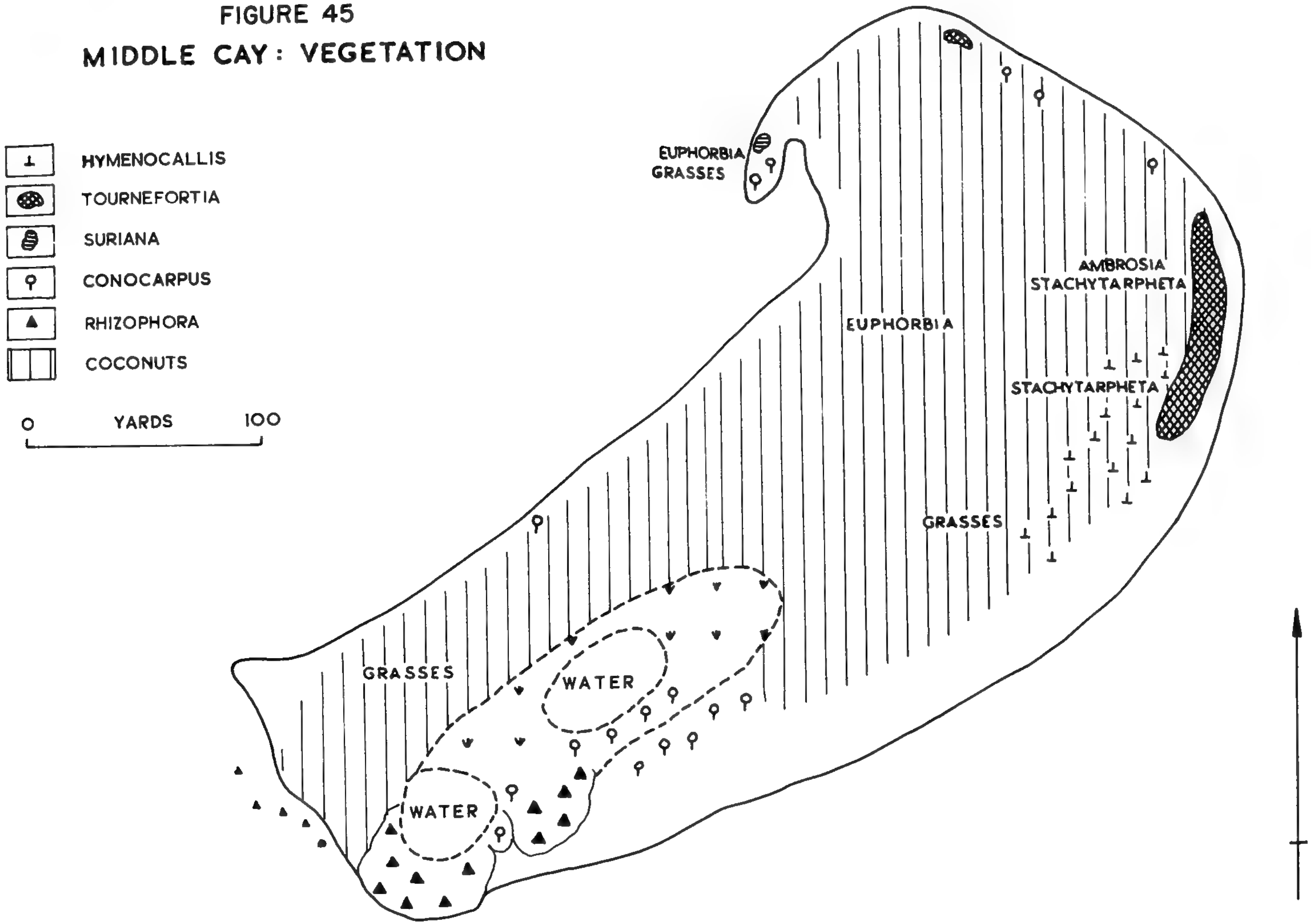


FIGURE 45

MIDDLE CAY: VEGETATION



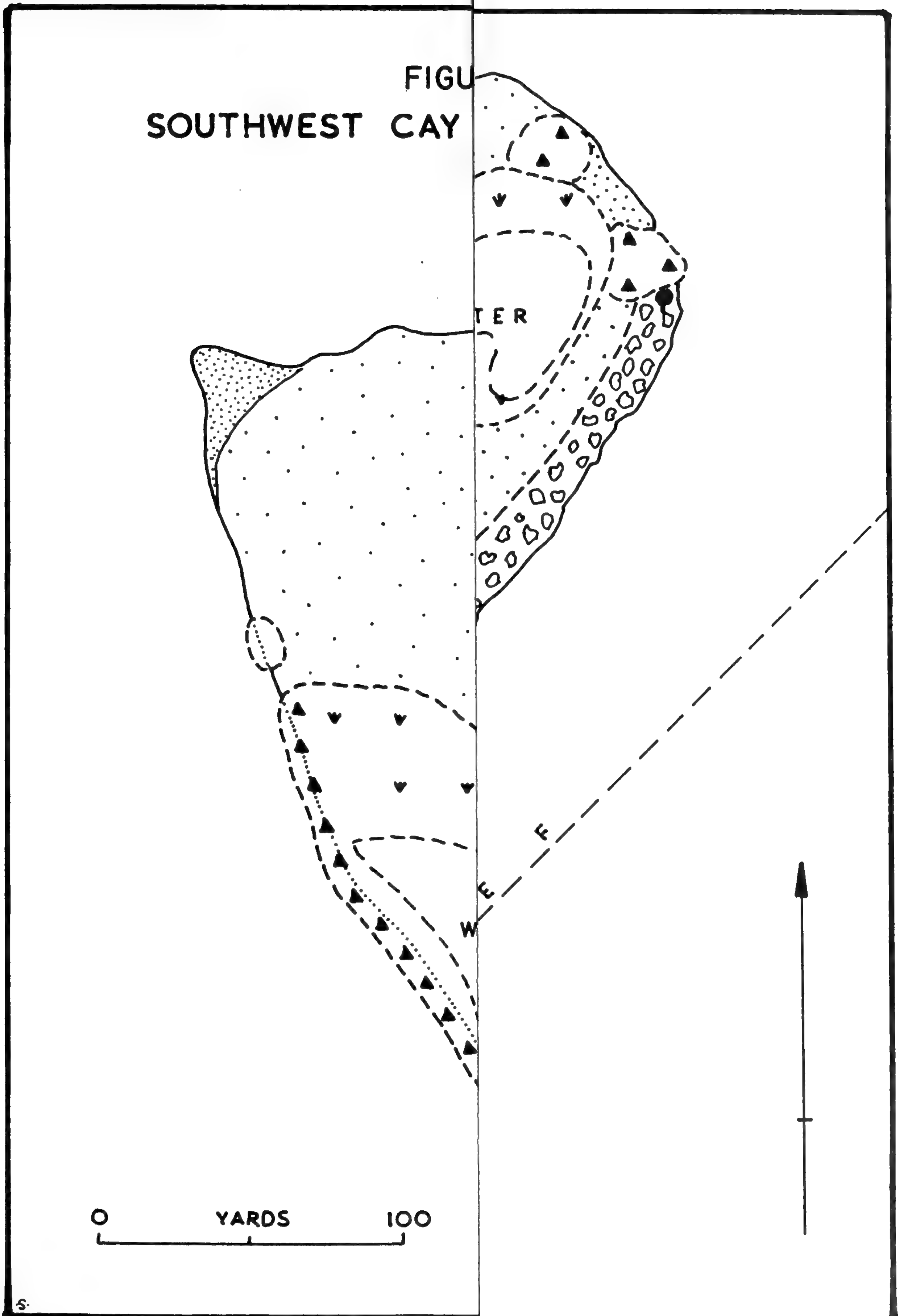
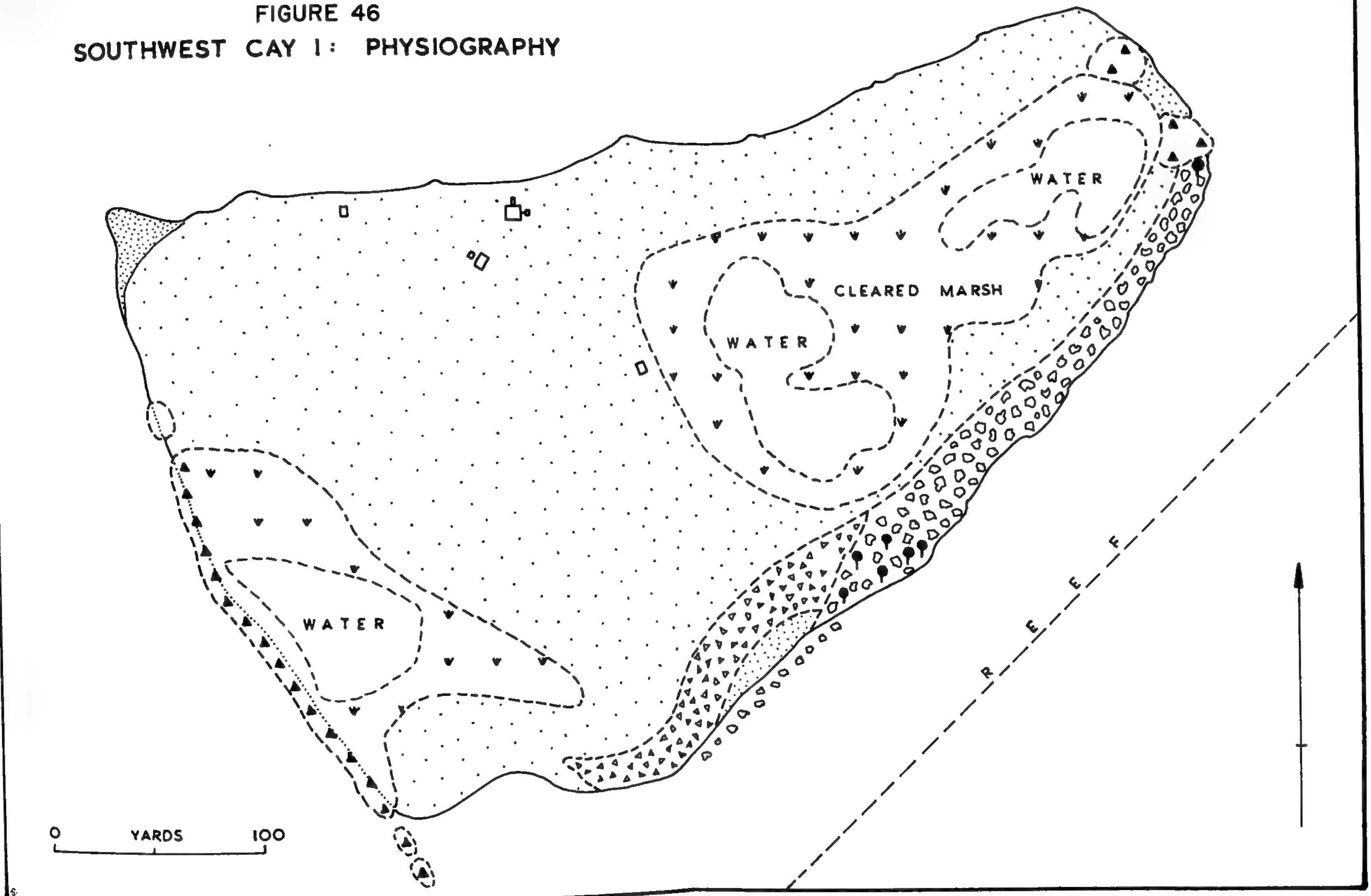

FIGU
SOUTHWEST CAY
TER
E F
W
0 YARDS 100

FIGURE 46
SOUTHWEST CAY I: PHYSIOGRAPHY



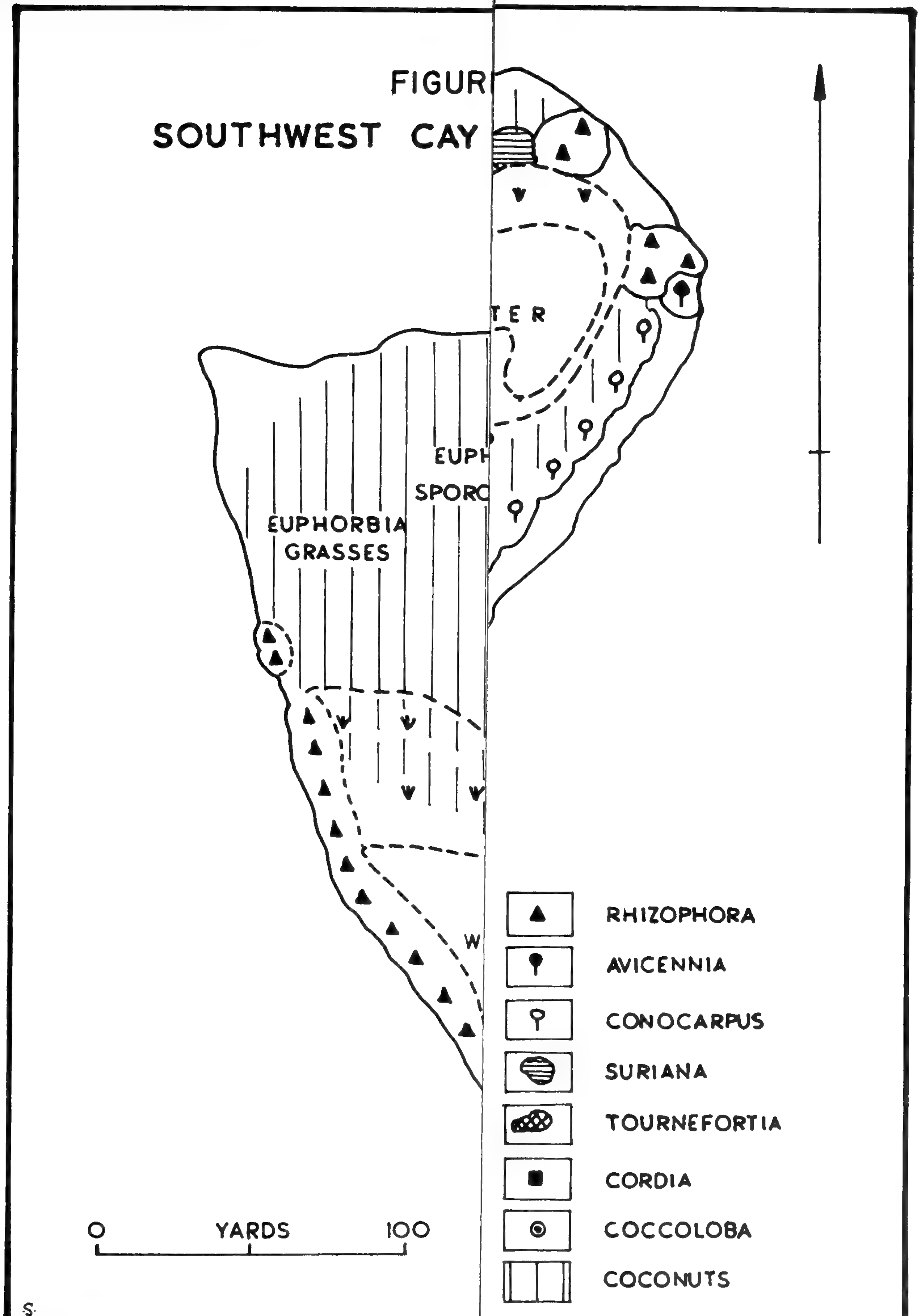
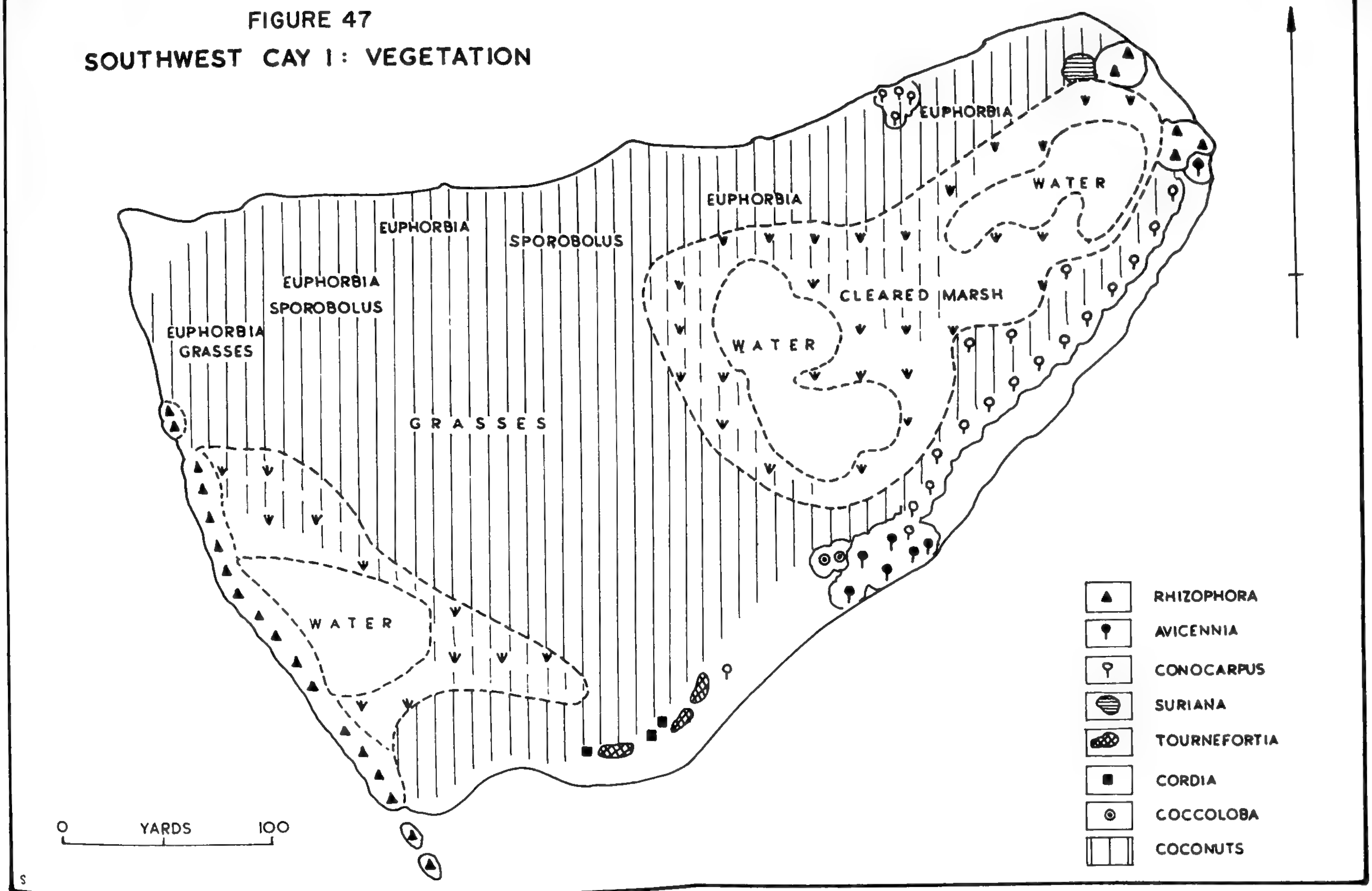

FIGUR
SOUTHWEST CAY
TER
EUPH
SPORC
EUPHORBIA
GRASSES
W
RHIZOPHORA
AVICENNIA
CONOCARPUS
SURIANA
TOURNEFORTIA
CORDIA
COCCOLOBA
COCONUTS
0
YARDS
100
S

FIGURE 47

SOUTHWEST CAY I: VEGETATION



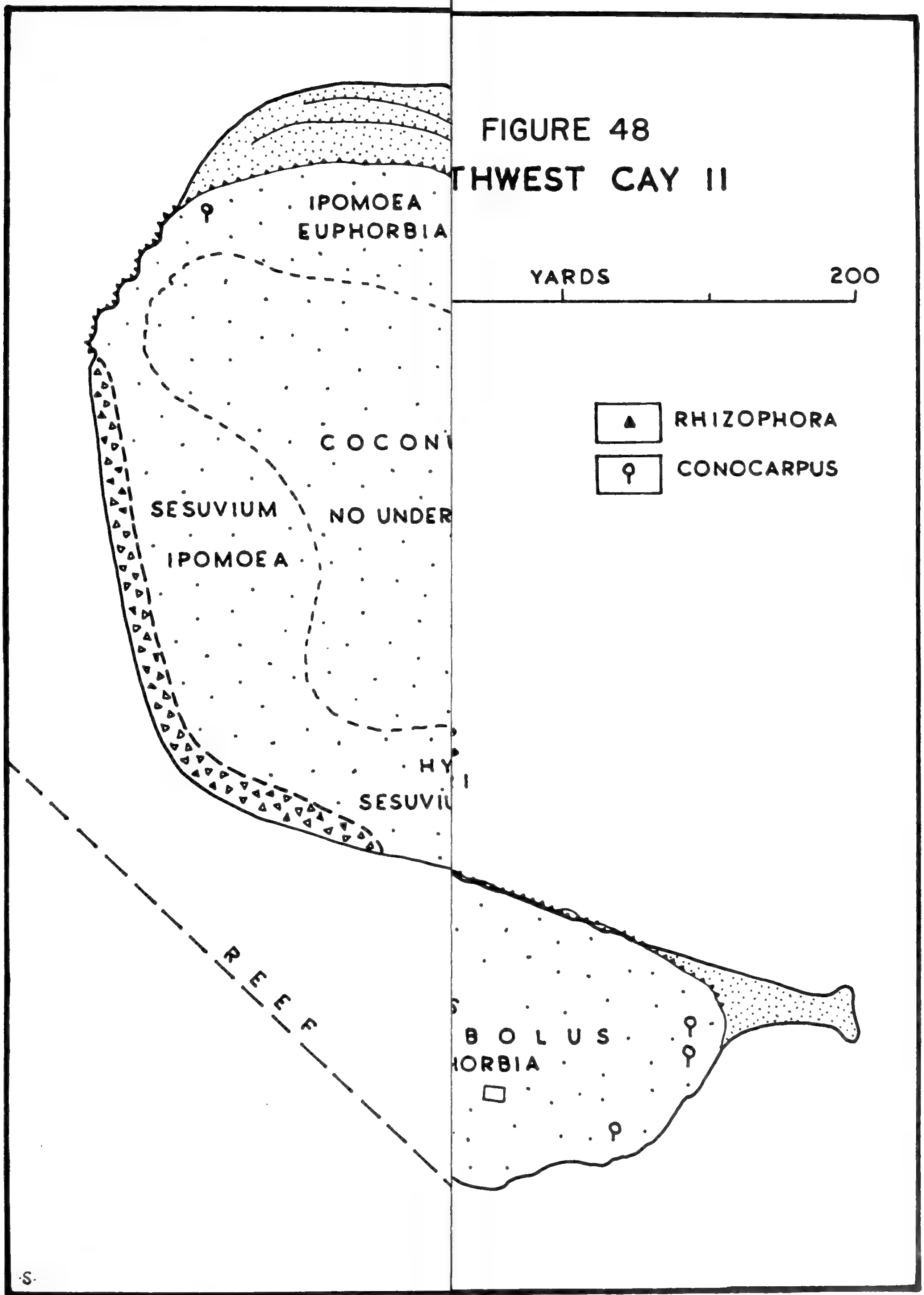


FIGURE 48
THWEST CAY II
YARDS
200
RHIZOPHORA
CONOCARPUS
IPOMOEA
EUPHORBIA
COCON
NO UNDER
SESUVIUM
IPOMOEA
HY
SESUVIU
REEF
BOLUS
ORBIA
S

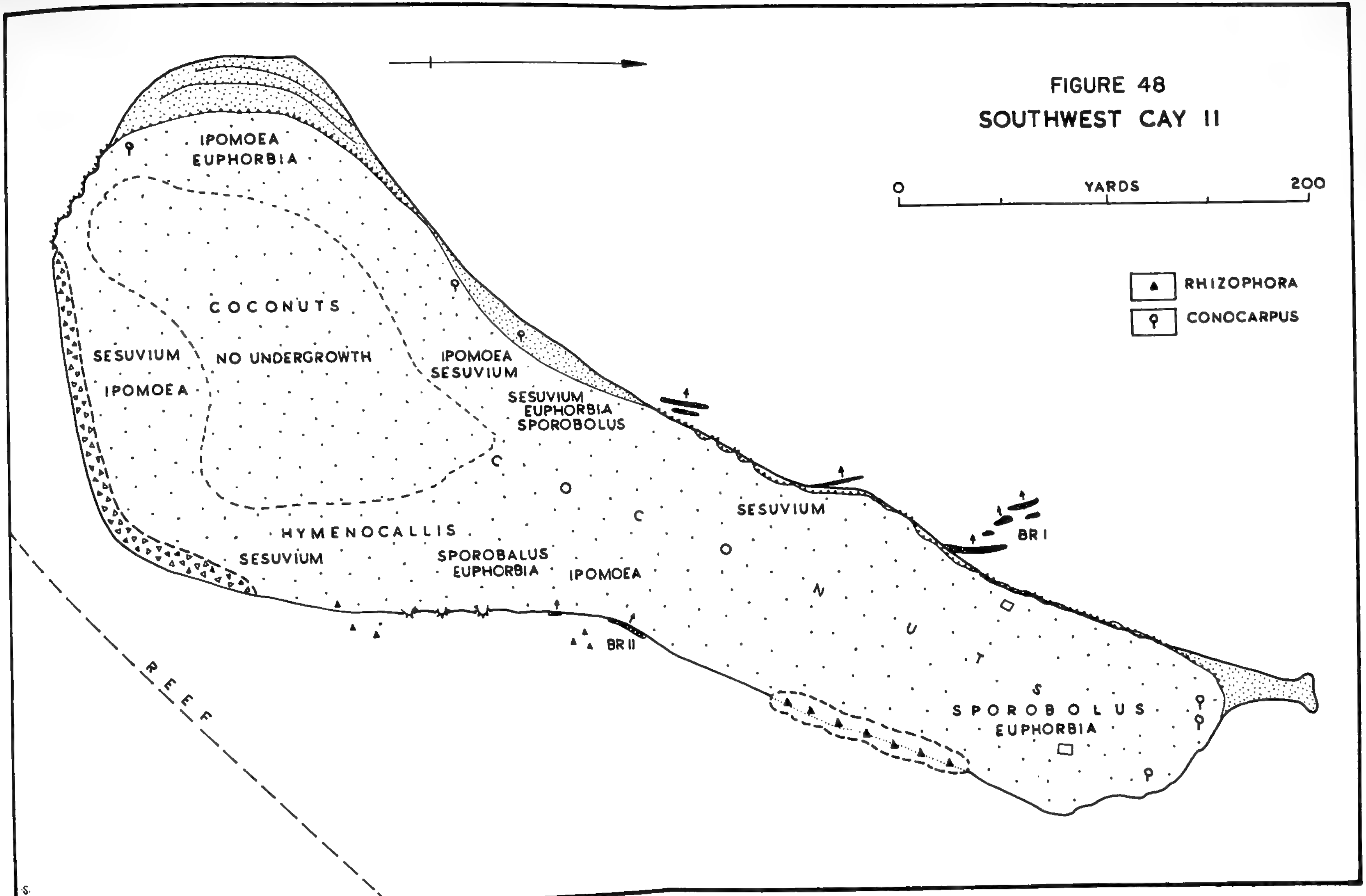


FIGURE 48
SOUTHWEST CAY II
0
YARDS
200
RHIZOPHORA
CONOCARPUS
IPOMOEA
EUPHORBIA
COCONUTS
NO UNDERGROWTH
SESUVIUM
IPOMOEA
IPOMOEA
SESUVIUM
SESUVIUM
EUPHORBIA
SPOROBOLUS
HYMENOCALLIS
SESUVIUM
SPOROBALUS
EUPHORBIA
IPOMOEA
SESUVIUM
COCONUTS
BR I
BR II
SPOROBOLUS
EUPHORBIA
REEF

VIII. FORM AND DEVELOPMENT OF THE CAYS

It is not proposed in this section to give a full review of the physiography of sand and mangrove cays: this must await the completion of work on the 45 barrier reef cays mapped during the two expeditions, when the results of both studies can be compared. Certain types of cays are unrepresented on the atolls; while conversely, some problems arising on the atoll cays find no counterpart on the barrier reef. This is not, therefore, a full analysis of cays and their problems; rather it is an interim report on the atoll cays, in which attention is especially directed to some of the main problems awaiting solution.

Vermeer in his study of the British Honduras cays classified them into "1. The coral sand cay. 2. The mangrove cay. 3. The mangrove-sand cay or transition type cay" (1959, 29). While this must be extended for the barrier reef cays, it is applicable to the atolls, where, as the detailed descriptions show, all three types are to be found.

A. The sand cays

Form of sand cays

Sand cays are developed near the inner edges of reef flats, generally on the windward reefs of atolls, and are usually--but not invariably--associated with reef-gaps. They are not found on the most exposed reefs, such as the east reefs of Lighthouse and Glover's Reefs, nor on the most protected. Ideally they are located at the northern or southern ends of linear eastern reefs, as on Lighthouse Reef, or on the more protected southeast reef of Glover's Reef. Turneffe is rather a special case, since its eastern reefs are protected from the prevailing winds by Lighthouse Reef; hence numerous small sand cays are found close to the reef-edge, in positions where they would certainly be destroyed were the reef more exposed.

Sand cays may range in size from small ephemeral unvegetated sandbores a few yards in diameter, to forested islands several hundred yards in length. The largest on the atolls is Half Moon Cay, 1100 yards long; the sand cays of Glover's Reef vary from 150 to nearly 700 yards in length; while the Turneffe cays are much shorter, being generally less than 200 yards long. Most of the cays are regular in shape, their width being one-third to one-fifth their length: variations may be caused by shape of the reef basement (Half Moon Cay) or accumulation patterns (Sandbore Cay). The cays are highest on their seaward side, where they overlook a shallow reef-flat; their surface slopes from the crest of the seaward beach towards the leeward shore, which faces a sheltered bay carrying at least 1 fathom of water.

Three main classes of unconsolidated material are present in the cays: rubble, shingle and sand. Rubble includes coarse coral blocks, dark-coloured and deeply weathered, which are too heavy to be thrown up the seaward shore of the cay, and have accumulated at the foot of the seaward beach. In some cases (Southwest Cay I, some of the Deadman Group) it forms the beach itself. Generally, however, the seaward beach is formed of shingle, chiefly small globular corals, broken larger

corals, and shells. The mean diameter of the material varies with exposure of the ridge, and varies from 1 to 6 inches. Shingle ridges may rise to a height of 10 feet above sea level, but usually do not exceed 5 feet. They are almost always single features, though two are described, one behind the other, at Long Cay (Glover's Reef). At the foot of each modern shingle ridge there is a smaller ridge of fine white shingle, 2-3 feet high, which contrasts strongly in colour and grain-size with the older, higher ridge against which it rests. The older ridges are thought to be storm and hurricane constructions, the small white ridges to be formed by day to day wave action. Finally, the area to leeward of the shingle ridge is formed of coarse coral-algal sand, often with a surface scattering of larger blocks and shingle ("rampart wash"). Fresh sand spits are frequently found building lagoonward from the ends of the cay, to enclose a sandy leeward shore. Where no shingle is found (some of the Turneffe cays, Sandbore Cay), the whole island is built from sand, rising to a crest on the windward side, and declining gradually to leeward.

Frequently the cay surface is not smooth, but descends to a central depression, containing a mudhole or lagoon, and rising to a leeward beach ridge. This feature is best developed on the most exposed cays, where the shingle ridges are highest, notably on Glover's Reef (where, however, the leeward beaches are exposed to considerable lagoon waves). The central depression is absent from most of the protected cays of the barrier reef. Soldier Cay, Turneffe, has a partly formed depression and leeward beach ridge at the north end of the cay.

Origin of sand cays

Sand cays are typically developed at gaps in linear reefs (Northeast Cay, Glover's Reef; Sandbore Cay, Lighthouse Reef), on small arcuate reef segments (many examples known from the barrier reef), or at prominent elbows or bends in reefs (Soldier Cay, Turneffe), but this relationship is not invariable. Some cays exist on unbroken reefs, and their origin demands an explanation (Cockroach and Deadman's Groups, Turneffe; Saddle and Hat Cays, Lighthouse Reef; Middle Cay, Glover's Reef). The presence of gaps or bends in reefs (i.e. variation in bottom topography) leads to refraction of surface waves (Munk and Traylor, 1947). Without refraction, waves simply sweep surface debris across reef-flats and into the lagoon, perhaps forming occasional short-lived linear sandbores, as reported along the north side of Glover's Reef. With refraction at gaps, however, and consequent opposed wave directions, waves both help to wash debris onto the reef-flat, and to keep it there. This was recognised in general terms by Charles Darwin (1842, 26), and later by Davis (1928, 13), but it was left to Steers to demonstrate it from field studies in Australia (1929, 250; 1930, 12; 1937, 13) and Jamaica. The effect of wave refraction on cay formation has been experimentally verified in the wave tanks at the Department of Geography, Cambridge. Here an arcuate 'reef' was built with bricks, its upper surface rising to water-level, and sand was fed in along the seaward edge of the reef. Waves approached normal to this edge and refracted strongly on either side. Sand was washed back across the reef and was halted by the refracted waves, to form an elongate drying 'cay' with its long axis parallel to that of the reef-patch. The stronger the

the waves striking the reef, the farther from the reef-edge is the cay formed, until with very strong waves all the material is washed off the patch into the lagoon. It is interesting that, given uniform wave conditions, no cay remains in existence perpetually: they tend to form and reform at 20 minute intervals until the lagoon is choked with sand. This series of experiments is proceeding.

Patterns of refraction in reef areas are well shown on a larger scale for Cocos-Keeling by Wood Jones (1910) and for Low Isles, Great Barrier Reef, by Stephenson and others (1931). The important point is the occurrence of refraction around the reef itself, rather than around the cay, and in theory the degree of refraction and hence the location of the cay on the reef-flat (the flat and bottom topography being assumed uniform) will depend on the degree of exposure and strength of wave action. All other conditions remaining the same, the cay will be formed further from the reef edge on exposed reefs than in less exposed areas, on deeper flats than on shallower ones. Thus Sandbore Cay, Lighthouse Reef, stands several hundred yards from the reef edge, whereas most of the Turneffe cays lie within a hundred yards of it. The fact that "all the sand cays are located at the back edge of the reef flat" (Vermeer, 1959, 113) does not in itself form evidence of refraction, as Vermeer argues: this condition is widespread but not universal, and simply indicates the degree of refraction involved, the size of the reef flat, and other complicating factors of cay evolution.

Cays are, therefore, accumulations of unconsolidated debris formed by the action of refracted waves. These wave patterns originate under the influence of prevailing winds, which on the British Honduras coast approach from the northeast, east and southeast, and, during the winter months, from the north (Section III). According to Umbgrove it is "the wind, and in a minor degree the breakers" which "forces the sand into a crescent-shaped sand bar" (1947, 734), but it is doubtful whether in British Honduras the wind plays any <u>direct</u> part in cay formation: it acts wholly through wind-generated surface waves. Much interesting work has been done in Indonesia on changes in cay physiography resulting from seasonal wind changes (Krempf, 1926, 1928; Umbgrove, 1929) and even longer-term climatic fluctuation (Verstappen, 1955), but it remains to be seen whether such changes can be demonstrated in British Honduras. Since the time of Hague, however, it has been known that relatively small seasonal changes in wind direction can lead to the growth of short-term sand-spits: some instances are given by Vermeer (1959, 114-115). Unvegetated cays, too, may appear and disappear seasonally: examples are known from the British Honduras barrier reef, and one is reported from Arrecife Alacran by Folk (personal communication).

There are three important factors limiting the influence of wave refraction, assuming an abundant supply of debris. One is the tidal range, here not more than a foot. Without such a small range many sand cays on exposed reefs simply could not exist, for the large waves crossing the reefs at high tide would wash all debris into the lagoon. Hence on the Australian Great Barrier Reef, where the tidal range may be over 10 feet, there are very few cays indeed on the outer reefs. High tidal range helps minimise it. In this connection British Honduras is

an ideal area for cay study on both practical and theoretical grounds. Secondly, the existence of a cay depends fundamentally on its reef basement--its depth and its extent. Cays can only be formed on reefs which lie within the vertical zone of wave action (Vermeer, 1959, 110-112), and British Honduras experience suggests that few cays indeed are built on flats carrying more than 3 feet of water. In this connection, Spender attempted to show that the type of sediment accumulation on cays was connected with the depth of the reef-flat (1930, 285-287), shingle ridges only appearing on the highest reef-flats, and pure sand cays on much deeper ones. Colman (1937, 143) reached similar conclusions in the Dry Tortugas, but his paper was never published. In British Honduras, on the other hand, all the evidence seems to favour Steers's contention (1937, 137) that exposure is the main control. Vermeer (1959) outlined more evidence for this view, and more is given in these reports. The factors governing cay physiography are so complex and inter-relating that to isolate one as a general control is to invite error, but if one control is to be named, within the framework of wave refraction, then, with Steers and Vermeer, I would choose degree of exposure in its widest sense. The area of the reef patch is of importance as well as its depth: if the patch is so small that the locus of cay growth by wave refraction lies lagoonward of it, no cay will be formed. Experiments suggest that in exposed areas reef-patches need to be larger for cays to form than in protected areas--as is often the case. Yet a third limiting condition concerns the debris itself, which varies greatly in grain-size and ease of transport: coarse material is more difficult to transport than fine, and hence will accumulate closer to the reef edge, thus forming rubbly cays on even narrow reef-flats. The more easily wave-transported finer sands will be entirely washed off narrow patches and will accumulate only on wide ones. These principles indicate some of the factors affecting cay location under relatively static conditions; little so far has been done on either the geometry of cays and associated reefs, or on the processes at work on them, and the subject may benefit by more refined experimental work.

One major problem, already stated, concerns the formation of cays not located at gaps or bends, bearing in mind the greatly diminished, perhaps negligible role of refraction. It is a problem which cannot at present be solved. The cays of eastern Turneffe (Deadman's and Cockroach Groups) form one class, where it can be suggested that cay growth is largely random following the accumulation of great amounts of detritus, with no other outlet, between the reef and the mangrove rim. In the case of Middle Cay, Glover's Reef, however, there is no barrier to the washing of debris into the lagoon, and one can only suggest that in certain cases cay growth obeys no general rules, but depends on the chance accumulation of boulders on the reef-edge, followed by sand accumulation to leeward of the obstruction. Chance accumulation may also account for such apparently short-lived cays as Saddle and Hat Cays, Lighthouse Reef.

Where a cay consists of sand and shingle, there seems some agreement (Wells, 1951, 3; Zans, 1958, 21) that the shingle ridge appears first, and that the embryonic cay then grows lagoonward by sand

accumulation, especially at the ends of the shingle ridge. Steers has asked whether, in the case of the Low Wooded Islands of the Queensland coast, the prior development of the shingle ridge might not derive the sand cay to leeward of its main source of debris supply, and this question is relevant also for some of the barrier reef cays of British Honduras. On the atolls, however, the sandy areas of cays are usually in such exposed locations that they could not survive without the protection of the shingle ridge, and hence could not have accumulated without its prior existence. No examples of shingle ridges without leeward sand areas are known from the atolls.

Constituents of sand cays

Having reviewed briefly the form and main reasons for development of sand cays, we may consider their material constitution. Since sediment analyses are not complete, this outline will be brief. The materials of sand cays fall into two groups: the loose, incoherent uncemented sediments, and the lithified rocks.

(a) Unconsolidated sediments.

On the atolls, unconsolidated sediments of sand cays range from fine sand to boulders, with coarse sands (0.5-2mm) and shingle (20-100mm) predominant. The sediments of all sizes are usually well-sorted, but sometimes bimodal. They are almost wholly organic in origin: and the mechanical properties of the sediment are closely associated with the type of organic materials which constitute it. Shingle consists largely of stony corals--small globular corals of the genera *Montastrea*, *Siderastrea*, *Diploria*, *Meandrina* and others, and broken fragments of larger branching corals, notably the *Acropora* and *Porites*. The grain size of the sediment depends largely on the proportion of particular corals in it; thus the first group are normally represented by abraded whole colonies, whereas the corals of the second group break down rapidly into "sticks" and "plates". *Acropora cervicornis* breaks down into cylindrical sticks 2-3 inches long and $\frac{1}{2}$ inch in diameter, *A. palmata* into larger more slabby plates 6 inches and more in length. The shapes of these particles make cay sediments difficult to analyse by normal methods, since conventional mesh sieves bear little relation to actual size and weight of coral fragments. Other constituents of shingle areas are calcareous algal nodules, especially in exposed areas, roughly cylindrical in shape and up to 4 inches long; *Strombus* and other shells, which locally form up to 40% of shingle ridges; and of minor importance, horny skeletons of soft corals, clumps of calcareous green algae, sponges, and driftwood. Rubble differs from shingle in its greater size (often in excess of 50cm diameter) and more irregular shape. It consists chiefly of the more massive coral heads (*Diploria*, *Montastrea*), subject to weathering rather than abrasion.

Cay sands similarly derive their characteristics from contained organisms sorted by wave action. The most important single constituent is the green alga, *Halimeda*. In the Pacific this alga is a major sediment contributor on deep lagoon floors (Funafuti: David and Sweet, 1904, 151; Marshalls: Emery, Tracey and Ladd, 1954; Kapingamarangi: McKee, Chronic and Leopold, 1959), whereas in the Caribbean evidence seems to be accumulating that it is of greatest importance in shallow water as a

beach constituent (Porto Rico: Van Overbeek and Crist, 1947; Jamaica: Steers and others, 1940). Sand analyses are not complete, but in British Honduras, Halimeda segments in places form small beaches containing no other material, and many beach sands, particularly near tide-levels, consist of 80-95% of this alga. This may result from the greater mobility of the flat, plate-like segments under wave-action, and their concentration in this zone, for away from the beaches, whole Halimeda segments form a lesser proportion. The segments range in diameter from 0.8-2mm; some are larger. A sand consisting largely of Halimeda will thus be concentrated in this size group, and have a very small standard deviation. In addition to whole Halimeda plates, cay sands contain broken Halimeda plates, Homotrema nodules in exposed situations, small amounts of tests and spines of echinoderms, sponge spicules, fish bones, shells and similar remains, and variable quantities of unrecognisable coral fragments.

The wide difference in characteristics and composition of shingle and sand on the cays is primary evidence of one most important factor in cay composition: the discontinuous breakdown of constituent organic material. The importance of discontinuous breakdown is well-known in fluvial landscapes, but is less studied with respect to cays. To take examples: A. cervicornis and A. palmata break down first into sticks and plates which vary in size within narrow limits, and then into constituent carbonate grains, with no intervening "fine gravel" stage. Halimeda breaks down into separate whole plates or leaves, each of which may split into two or three parts before disintegrating into fine particles. Larger globular coral heads in the zone of wave action seem to pass directly to the constituent particle stage. These changes are brought about mainly by mechanical abrasion of sediments, partly by chemical and biologic breakdown.

Many studies have been made (Otter, 1937; Bertram, 1936) of the breakdown of corals by boring algae, molluscs, fish, echinoderms and other organisms. On the atolls Scarids were frequently seen rasping the surface of coral boulders, and Holothurians were seen in great numbers excreting characteristic cylindrical rods of sand-size material, but we made no special studies on their role in rock comminution. However, attention may be drawn to one means of coral breakdown, active on cay surfaces beyond the zone of wave action, seen over wide areas. This is the splitting of globular colonies (single heads) by radial fracture, generally on heads 1-2 feet in diameter. It occurs mainly in Montastrea annularis, M. cavernosa, and Diploria clivosa, and was seen on one occasion in Colpophyllia natans. It presumably results from some form of chemical weathering, and specimens have been taken for analysis. The primary splitting is into perhaps half a dozen pyramidal segments, and the process is repeated, until the end products are cuboidal segments of rock ½-3/4 inch long, which themselves disintegrate to coarse sand. Species can often be determined until the penultimate stage. Breakdown of this sort must be a major means of comminution away from wave action.

Clays and silts are not found on cays, at least not in significan quantities.

The British Honduras sediments agree in most essentials with those of Arrecife Alacran studied by Folk and Robles (I am much indebted to Dr. Folk for sending me a copy of his unpublished paper), but differ considerably in organic content from other areas. Thus at Bikini, beach sands contain up to 60% Foraminifera, including the large foram Marginopora reaching 5 mm in diameter (Emery, Tracey and Ladd, 1954, 36-37); while in the southern Carolines the orange foram Amphistegina forms up to 98% of lagoon beach sands at Kapingamarangi (McKee, Chronic and Leopold, 1959, 509-512). Foraminifera nowhere form an important constituent of beaches on the atolls, and those which do occur on the reef-flats and in the lagoons (Cebulski, 1961) are microscopic forms, which cannot long resist wave abrasion when mixed with larger material. Alcyonarians are not well represented in beach sands, in contrast with the dominance attached by Cary to them in the Dry Tortugas and Samoa (1918, 1931 and other papers), though they probably contribute to the large amount of small calcareous fragments which are no longer identifiable. Halimeda at Bikini is "usually rare" (Emery, Tracey and Ladd, 1954, 36), is absent in the Hawaiian Islands (Emery and Cox, 1956, 383), and is not mentioned in the Kapingamarangi beach sands (McKee and others, 1959), in contrast to its importance in the Caribbean. In sands, as opposed to shingles, fragments derived from stony corals and from calcareous algae are probably of nearly equal importance in British Honduras, especially in the lower grade sizes where identification is difficult.

Finally, a note on "erratic" sediments on atoll islands. These are of four types: pumice, lava, quartz, and brown limestone. Pumice is everywhere widespread on coral islands, and can often be used in dating when correlated with known eruptions. Miss Sachet has reviewed its distribution, and noted the lack of evidence so far from the Caribbean (1955, 27). Vermeer (1959, 121) mentions that "rounded pieces of pumice....found on many of the cays appear to have been carried....from the volcanic Windward Islands to the offshore area of British Honduras and then thrown up on the cays by the wind driven surface waves and current." The distribution of pumice on the cays is erratic: one cay may have abundant pumice and a nearby island very little. Generally, it is more abundant on the exposed cays of Lighthouse Reef, Glover's Reef and the southern barrier reef, than on Turneffe and the northern barrier. The greatest amounts are found on the southern barrier reef cays. Most of the pumice is in small rounded pieces 0.5-2 inches in diameter, but there are numerous smaller fragments, and some larger ones up to 9 inches long. The pumice is silver-grey when fresh, often blackened on the outside, and has undergone some weathering. It does not form distinct zones on cays, as in some reef areas, and cannot be used for dating or as evidence of shoreline change. It seems to be accumulating at a fairly steady rate.

The second rock, a lava, is much less common, but a number of specimens can soon be found by searching shingle ridges, as at Half Moon Cay. It forms subrounded blocks up to 6 inches long. Dr. C.L. Forbes of the Sedgwick Museum, Cambridge, kindly comments that it is a very vesicular scoriaceous lava, red in fresh section, weathering to yellowish-brown

with many black spots which may be original or a weathering product. The zone of weathering extends inwards for $\frac{1}{2}$ inch from the surface of specimens. The lava contains shell inclusions. It does not float in water, and has probably been brought in tree roots (Emery, 1955).

The third rock, white quartz, is known only from a single specimen 1 inch in diameter picked up by Murray on Middle Cay, Glover's Reef. It, too, has presumably been rafted in by floating trees: suggesting an origin for both lava and quartz on the relatively close Honduras and Nicaraguan coasts, rather than in the Lesser Antilles.

Finally, the brown limestone, known from Half Moon Cay is rounded large pebbles up to 1 foot in diameter. I am indebted to Dr. Forbes for examining this rock in thin section and making the following observations: "The rock is a calcarenite with subordinate quartz sand and is much recrystallized. This means that it originated as a sand of which the grains were formed from a pre-existing limestone, being cemented by the addition of more lime to form the present rock. The small amount of quartz sand was presumably blown in by the wind or washed in by water before the final cementing. The limestone of which most of the sand-grains are composed, is of an obscure nature, but was most likely a calcilutite, I think. It could have been formed from a fine-grained calcareous mud, such muds being common deposits of warm marine lagoons. Thus, the rock could represent an earlier episode in the history of the place where you found it. But it could equally well have been brought in from some other region, along with the scoriaceous lava and pumice samples you showed me. (The white material filling pipes in the rock is also carbonate of lime presumably precipitated from vadose ground water in the burrows of organisms, in holes left by decaying plant-roots, or simply by replacement of the limestone along passages of easier permeability)."

None of these "erratic" rocks are of any quantitative importance in cay formation, though pumice may form a very local ground cover.

(b) Consolidated sediments

Lithified rocks on reef islands are of such variety and in some cases so difficult to distinguish that they may be incorrectly mistaken for each other and false conclusions as to their origin drawn. The more common types of rocks on reef islands may be grouped as follows (there are probably others):

1. Oolites and aeolianites dating from an earlier period in the island's history. Aeolianites are well seen in Bermuda (Agassiz, 1895), and oolites in the Bahamas (Newell and others, 1951) and on Pedro Bank (Zans, 1958, 8-11); they have not been seen in British Honduras.

2. True elevated reef rock, characterised by the presence of corals in the position of growth in a matrix of other calcareous sediments, described for example by Gardiner (1903-6) and Seymour Sewell (1935, 1936) in the Maldives. At lower elevations this may appear as the "honeycomb rock" of Stephenson and others (1931, 53, 101). It has not been certainly identified in British Honduras, except for small areas along the windward reefs of Lighthouse Reef.

3. Shingle conglomerate and shingle limestone. Shingle conglomerate was the name given by Stephenson to "recently cemented platforms of coral debris... everywhere more or less compacted together by means of mud and silt to form a hard rock" (Stephenson and others, 1931, 25). In Queensland it is formed from lithified shingle ridges on low wooded islands. In the Houtman's Abrolhos, Teichert sharply distinguished "rocks that result from the cementation of intertidal deposits largely composed of coral fragments. As far as the Abrolhos are concerned a clear distinction between shingle beach ridges and shingle limestones has always been easy to make, for nowhere were consolidated beach ridges found, and shingle limestone deposits are normally of such a nature as to suggest formation in the zone of breakers slightly outside the zone in which beach ridges are built" (Teichert, 1947, 152). The two deposits can best be distinguished, it seems, by their physiography and field relations.

4. "Promenade Rock". The exact status of this is uncertain; it has been described from the Great Barrier Reefs and from the Morant Cays, Jamaica. On the low wooded islands of the Queensland coast, Steers speaks of "a platform or promenade of coral conglomerate" (1937, 119), which may be "a cemented, ancient, and presumably raised rampart" (1937, 27)(cf. 1929, 252-56, and Spender, 1930, 209-210). Steers later gave this description of promenades on the Morant Cays: "The Morant promenades are made essentially of beach rock, with larger fragments of coral and shells. They are always to windward of the cay; they are very rough in detail, but appear level from a short distance;... they often show clear dips, but these dips are not consistent in direction. At first sight, they can easily be taken as raised features, especially as they are often partly covered with Sesuvium and grass and are about a foot above mean sea-level, but there is nothing to prove it. ... What is difficult to explain is their flat upper surface" (1940b, 309); and again: "They are mainly composed of cemented sand and... are of the same nature as ordinary beachrock; they may contain shells and coral fragments. Their outer and upper surfaces are eroded into very jagged forms. Apart from the detailed erosion forms, the average surface is often remarkably level, and from about 12 to 18 inches above high water mark; it is this characteristic which makes the term 'promenade' applicable. ... The outer surface layer of the promenade, about a quarter to a half an inch in thickness, was usually hard and compact, and stalagmitic in appearance when broken. ... The promenade rock often shows clear dips, but they are not regular in direction. The promenades occasionally show long and fairly straight cracks or joints, not in any particular arrangement, but on a considerable scale" (1940a, 39-40).

These descriptions have been quoted at some length because of their similarity to some of the Half Moon Cay exposures described in Section VI. Steers did not think the Morant promenades should be too closely compared with those of the Great Barrier Reefs, and left the question of their origin open, in the hope that work elsewhere, especially in British Honduras, might provide a solution (1940a, 40; Steers and others, 1940, 310). Unfortunately promenades are not common in British Honduras, even on the most exposed cays, nor are they found

on Pedro Bank, where the similarities with the Morant Cays might be expected to be greatest (Zans, 1958). I doubt whether they indicate uplift, at least in the sense of a eustatic fall in sea-level, since, as Spender pointed out (1930, 210) we should in that case find more extensive remnants in more sheltered positions.

In parenthesis the formation of "ironshore" on tropical limestone coasts may be mentioned, since it may conceivably be confused with promenade rock. Ironshore only seems to form on coasts of solid carbonate rock, and has been widely described in the Caribbean (Caymans: Matley, 1929, Doran, 1954; Cozumel and mainland Yucatan: Edwards, 1957, 23-28; Ruatan, Bay Islands: Richards, 1938; San Andres, Nicaraguan coast: Parsons, 1956); but it is not found in British Honduras even on those sections of the mainland coast where limestone forms low cliffs. Parsons (1956, 55) considers it the same as the Morant and Queensland promenades, but such a conclusion seems dubious.

5. Intertidal beachrock and intertidal beach conglomerate. These are undoubtedly the best known lithified materials on sand cays and other tropical beaches. They seem to be mainly intertidal in origin, and generally form ribbons following the shore, dipping seaward at the angle of the beaches. Beachrock is found either on windward or leeward sides of cays, but never wholly surrounds them. In British Honduras, most of the outcrops occur on the windward side of cays, where erosion is currently taking place, and only rarely on prograding lagoon shores. There are many recent reviews of the beachrock problem (Emery and Cox, 1955; Ginsburg, 1953; Kaye, 1959; Russell, 1959), but no agreement has been reached on its origin, the most difficult factor to explain being its patchy distribution. It occurs in British Honduras on cays too small to have appreciable fresh water seepage through cay sands, as Gardiner (1931, 40) and others supposed; and it is found on both very exposed and very protected shores. All the incipient (newly exposed, poorly indurated) beachrock (BR II at Northern Cay, Lighthouse Reef; Deadman I, Turneffe) is in a very sheltered location, with the exception of that at Middle Cay, Glover's Reef; this is also the case on the barrier reef cays. The suggestion that blue-green algae are active agents in cementation has been disproved (Krauss and Galloway, 1960).

6. Rocks formed by cementation of sands in cay interiors, including the "cay sandstone" of Kuenen (1933, 86-88) and Seymour Sewell (1935, 502ff.), and the phosphate rock widespread in the drier parts of the Pacific (Fosberg, 1957). This group has not been certainly identified on the atolls, though it may occur at Harry Jones, Turneffe, and in the interior of Half Moon Cay, Lighthouse Reef. Sewell was "by no means fully convinced" of the distinction between cay sandstone and beachrock (1935, 501-502).

This review illustrates the diversity of rocks recognised by reef workers; of them, only the beachrocks have been investigated with any thoroughness. The difficulties of differentiating between the groups of reefrock, shingle limestones and conglomerates, promenade rock and intertidal beach conglomerate have been illustrated in the account of

Half Moon Cay in Section VI. One cannot emphasise too strongly the need for caution in interpreting lithified materials at this stage. The facts of distribution alone suggest that these and similar rocks, which at first sight may seem to indicate relative uplift, may in fact be lithified storm or hurricane constructions. To take a recent example: some months after Typhoon Ophelia at Jaluit Atoll, Marshall Islands, the reef-flat was partly covered with "broad, low tracts of imbricated slabs and boulders" developed from storm ridges (Blumenstock, Fosberg and Johnston, 1961, 619). If these are lithified, into what clear category will they fall--shingle limestone or conglomerate, beach conglomerate, or promenade rock? "There are necessarily, at the present stage, many structures described in the existing accounts of coral reefs of which one can only say with Professor Sollas (Funafuti Report, p. 24): 'I do not understand it, and forbear from speculation'" (Stephenson and others, 1931, 91).

Relict beachrock and present evolution of sand cays

Assuming that true beachrock is essentially intertidal, then it becomes a valuable tool in interpreting cay history. To some extent it forms an "armourplate" against cay erosion, but its success is not invariable, and once a beach shifts under wave action a line of relict beachrock may be left as evidence of its former position. Multiple shifts leave multiple lines of beachrock, recording position and orientation of former beaches. The record is not complete: beachrock is notoriously patchy in distribution, and may be either subsequently covered by fresh beach sands, eroded away, or itself broken and moved by wave action. Russell (1959) has shown how beachrock exposures may alter drastically with seasons, and there is no doubt that many inconspicuous exposures are not seen by investigators, even in careful surveys. Much attention was devoted during both expeditions to mapping relict beachrock in shoal water near cays, and several general conclusions emerge. In most cases, lines of relict rock record continuing migration of cays away from reef edges and reef openings, back across the reef flat towards the lagoon. Cays are eroding to windward, aggrading to leeward, and very little beachrock is thus exposed on lee shores (an exception is Southwest Cay II, Glover's Reef, discussed in Section VII). This is in striking agreement with evidence from other areas, including the Maldives (Gardiner, 1903-6; Seymour Sewell, 1935, 516-517, 1936, 85) and the Carolines (McKee, 1958, 248-249). There is also a tendency, noted particularly on the barrier reef cays, for the outer, presumably older lines of beachrock, to lie at a lower level than inner newer lines: some even form a base for branching corals, which would be impossible in their original intertidal location. This evidence is discussed elsewhere (Stoddart, 1962), and taken to indicate slight drowning of the cays in modern times, perhaps associated with the present climatic amelioration: but the difficulties of such an interpretation are stressed.

There is much other evidence of erosion on cays, chiefly in the form of undercut cay margins, toppled coconut trees, and unusual shape of cays. Undercutting has been almost universally noted in the detailed cay descriptions. Kuenen noted the same phenomenon in Indonesia (1933, 1950; also Sewell in the Indian Ocean, 1935, 512-518), and interpreted it as evidence of a fall in sea-level of the order of 2 metres; several

workers have recently adopted this as an essential element in reef theory (Cloud, 1954; Wiens, 1959). Vermeer (1959) described evidence which in his opinion showed a similar 5-7 foot fall in sea level in recent times in British Honduras. There is no evidence of this on the atolls (Sections V, VI), and none on the barrier reef which can be regarded as substantiated beyond reasonable doubt. The question of such a 6 foot fall is discussed with reference to the reefs in Section IX, but it can be stated here, quite unequivocally, that if the sea level stood 6 feet higher than now, the cays as we know them would simply not exist. None of the cays are so high that they cannot be referred to a sea-level at or near the present; conversely, if such a stillstand did take place, cay development must have been weak in the extreme, for while present seas can build ridges 10 feet high, the 6 foot seas can only have constructed beaches 3-4 feet high. Further—and this is a significant point—rise of sea level by 6 feet would have the effect of increasing degree of exposure, considerably altering patterns of wave refraction, and moving the locus of cay accumulation lagoonward. The only way out of this dilemma is to assume that the reefs grew up entirely to the 6 foot level, and have subsequently been completely planed away: an improbable circumstance in the 2,000 years which Fairbridge (1961, 168-169) allows. If this stillstand can be demonstrated on the British Honduras cays, which after much detailed work I regard as very doubtful, then the cays must all postdate it, and be less than 2,000 years old; this, too, I find improbable.

There remains the possibility of minor fluctuations of sea-level. The evidence consists of the undercutting noted, which is generally in beaches 2-4 feet high, and has nothing to do with a 6 foot stillstand, and of raised beachrock. The undercutting is almost universal on atolls and barrier reefs, the raised beachrock limited to Lighthouse Reef and Turneffe. No raised beachrock or other lithified material is found on the barrier reef or Glover's reef, and for this reason cannot indicate a eustatic fluctuation. In the case of Turneffe and Lighthouse Reef it seems to indicate positive local uplift, and the case of Turneffe is briefly discussed below. This leaves little but the undercutting. One may follow Kuenen and believe that a fall in sea-level will lead to erosion of the cay by erosion of its foundation--in which case, why are raised beachrock and reefrock not more widespread? Or one may consider it to result from a slight rise in sea-level shown by drowned beachrock, in which case it should be a world-wide phenomenon. This drowning is estimated at about 4 inches in the last century, increasing in rate in the last 20 years (Fairbridge, 1961, 102-105). It may be significant that in those areas where the raised beachrock is found, undercutting of cay margins is very poorly developed. Speculation on such limited evidence is bound to be dangerous, and the question is best left open at this stage. However, we may note that a deepening of water to this extent is equivalent to increasing the degree of exposure, and hence in shifting the locus of cay accumulation lagoonward. The known rise is small, but still considerable when compared with the tidal range.

Fortunately we are able to estimate in one case (Sandbore Cay, Lighthouse Reef) the rate of cay erosion and migration, at approximately 1 yard per annum, becoming more rapid in the last 15 years. This figure is probably much too high for most cays, since Sandbore is

in an exceptionally exposed position and is unprotected by shingle ridges. Detailed mapping over a period of years should lead to more reliable data. Whether the cays are decreasing or increasing in size is a moot point, which has been argued for other areas. It has been suggested that as the seaward shore retreats further from the reef edge, the waves reaching it will be less powerful and erosion will slow down, without any necessary retardation of lagoonward growth. On the other hand, in their migration lagoonward, many cays have now reached the inner limit of the flat on which they stand. Verwey (1931, 203) published a diagram showing a cay extending lagoonward on the flat on its own detritus, without perhaps realising the vast amount of material required. Once a cay begins to be pushed off its reef flat, it will rapidly decrease in area and may disappear altogether; evidence indicates that this stage is now being reached on the British Honduras reefs.

Turneffe: a special case

The sand cays of eastern Turneffe form a special case, distinct from cays elsewhere in British Honduras. The following facts are relevant: At Soldier Cay, where the atoll is widest, there is a short section of exposed, drying reef along the main eastern reef. At nearby Harry Jones there is a tilted beachrock rising to 2 feet above the sea. Extending north and south from this point, along the east side of the main mangrove belt, is a sand ridge, which is underlain by the Harry Jones beachrock, and hence must have shared in its uplift. North and south of the ends of this sand ridge, where the atoll begins to narrow, are a number of atypical sand cays, located back of unbroken reefs on unusually shallow reef flats—the Deadman Group in the south, the Cockroach Group in the north. These may represent a stage in the development of a continuous sand ridge. It is suggested, as a point for discussion, that this is in fact the case, and that these facts taken together show slight recent warping of the Turneffe bank, reaching a maximum in the Harry Jones-Soldier Cay area, and decreasing north and south. This would also help to explain the development of the Deadman and Cockroach Groups. For reasons already made clear, we cannot accept eustatic fluctuations of sea level as explanations of these several features.

Effect of hurricanes on sand cays

The incidence and effect of hurricanes have been briefly noted in Section III. Elsewhere their general effects are well known, witness the accounts of the 1934 cyclone at Low Isles, Great Barrier Reef (Moorhouse, 1936), and the devastations of Arno Atoll recorded by Wells (1951, 5-7). Recently hurricane effects have been studied in great detail following Typhoon Ophelia at Jaluit, Marshall Islands, in 1958 (Blumenstock, 1958a, 1958b, 1961; McKee, 1959). A recent resurvey at Jaluit indicates that some of the changes may be only temporary interruptions (Blumenstock, Fosberg and Johnson, 1961). Long term effects may be summarised from British Honduras data as follows:

1. Catastrophic erosion of cays, which in conditions of rising sea-level cannot easily be repaired; illustrated by Saddle Cay, Lighthouse Reef. This may lead to

2. Destruction of cays, where the whole island is washed away. This can be well illustrated from the barrier reef, not so easily from the atolls. The second of the Pelican Cays, Turneffe, and Bushy Cay, Glover's Reef, may have disappeared in this way. Once a vegetated cay is destroyed and replaced by a "second generation" sandbore, a long period must elapse before chance colonisation by vegetation takes place, if at all. About six cays have disappeared in recent years through hurricane activity; indeed, many areas now lacking cays, where islands might reasonably be expected (such as reef gaps), may be only temporarily without them, and search may well show traces of beachrock at these points.

3. Physiographic effects include the exposure of beachrock and other rocks as shores shift under hurricane wave action, as at Half Moon Cay; the stranding of large boulders as at this cay and Middle Cay, Glover's Reef; the breaking up of beachrock; and the accumulation of large rubble on reef-flats, as at Soldier Cay, Turneffe. "Rampart wash" and fresh sand carpets may be largely hurricane deposits.

4. Effects on vegetation: these are difficult to determine in the absence of previous surveys, and only aligned fallen coconuts (Glover's Reef cays) can be ascribed to hurricanes at present. Hurricanes may help to account for the haphazard distribution of some species of plants on cays, and for the destruction of mangrove areas, revealed by abnormally low regrowth compared with other areas.

These are all very general observations. However, it is hoped that the physiography of the atoll cays is described in sufficient detail in this paper to make possible accurate estimates of the effect of future hurricanes. In this respect, regular resurveys to establish long-term changes are required (perhaps every decade), to distinguish these from hurricane effects, which ideally should be assessed as soon as possible after the damage.

Vegetation of sand cays

Little will be said here concerning cay vegetation, partly because I have no botanical knowledge, partly because present vegetation patterns on cays are so artificial and ephemeral. The startling change in appearance of many cays between the two expeditions, and the record of clearing at Half Moon Cay, is sufficient evidence on this point. A large number of cays are now virtually unvegetated apart from coconuts, while the ground vegetation of most of the remainder is subjected to repeated cutting back, particularly on inhabited cays. Vegetation, however, is of the greatest importance in stabilising sand cays, more so in my opinion than beachrock, yet very little is known of reef island ecology and flora in the Caribbean. Millspaugh has described the Florida Keys (1907) and Alacran (1916), Bowman the Dry Tortugas (1918), Howard Bimini, Bahamas (1950), and Børgesen the Virgin Islands (1909). The most relevant regional accounts have been those of Asprey in Jamaica (Asprey, 1959; and Robbins, 1953; and Loveless, 1958), Chapman on the Jamaican cays (1944; Steers and others, 1940), and J.H. Davis on the Florida Keys, Dry Tortugas and Marquesas (1942). Sauer (1959) has published a recent survey of coastal pioneer plants of the Caribbean and Gulf of Mexico, based on wide-ranging field studies.

The dominant vegetation of the cays is the coconut, Cocos nucifera, though it is probably not native to this region (Bruman, 1944; Beccari, 1917). According to Edwards, the only references to coconuts in the Relaciones de Yucatan refer to plants imported from other Spanish possessions (Edwards, 1957, 100). He comments (p. 89): "It may have been brought from the West Indies by the early Spaniards and planted in Yucatan, but we find no mention of its occurrence along the Caribbean coast of the peninsula until the latter part of the Nineteenth Century." However, coconuts were widespread on the sand cays of British Honduras by 1810 (Henderson, 1809; 1811, 21-22), and were established on the atolls at least as early as 1720 (Saddle Cay, Section VI). They have probably greatly increased in importance in the last 50 years.

In their natural state the cays may have supported broadleaf forests, of which traces remain only on Half Moon Cay, Lighthouse Reef, and Northeast Cay, Glover's Reef. The dominant constituents are Cordia sebestena, Bursera simaruba, Bumelia retusa, Pithecellobium keyense and Pouteria campechiana, with perhaps sapodilla and mahogany. Pinus caribaea, found on one of the uninhabited barrier reef cays, is not seen on the atolls.

With the exception of cocal and restricted broadleaf forest, the vegetation of the cays falls into six groups: (a) strand plants; (b) marginal thicket; (c) interior thicket; (d) other interior areas, chiefly grass; (e) marsh and swamp; (f) mangrove. The strand plants include those species, many pan-tropical, common to sand beaches—an outer zone of Sesuvium portulacastrum and Ipomoea, an inner zone with the hardy colonising grass Sporobolus virginicus and other plants such as Euphorbia and Canavalia. Sesuvium is found on both shingle and sand, Ipomoea generally on sand. The "marginal thicket", lying landward of the strand zone, differs according to substrate and exposure: in exposed shingle areas Tournefortia gnaphalodes and Cordia sebestena are most common; on less exposed sand shores they are replaced by Suriana maritima and Coccoloba uvifera. The "interior thicket" is less well known. Besides Suriana it includes Conocarpus erectus, Erithalis fruticosa, Rivina humilis and Ernodea litoralis. Areas not covered by thicket are generally under coconuts, with an undercarpet of low herbs (Stachytarpheta jamaicensis, Wedelia trilobata, Ambrosia hispida, Cakile lanceolata), the grasses Andropogon glomeratus and Cyperus planifolius, the lily Hymenocallis littoralis, and the legume Sophora tomentosa. The vegetation of interior marshes has been almost entirely removed, and they are now usually covered by a mat of Wedelia trilobata, which seems to prefer damp, shady locations, with a few relict mangroves. The mangrove zone is not, by definition, well developed on sand cays, and is represented only by scattered mature trees round cay margins, and innumerable Rhizophora seedlings in shoal water offshore.

The strand plants are evergreen, fleshy, and adapted to cay conditions (thus Sesuvium leaves are plump and fleshy in direct sunlight, thinner in shade; while Tournefortia and Sophora show xerophytic adaptations). No cacti are found on the atoll cays which distinguishes them from the Jamaican and Florida cays, nor are cultivated fruit trees, in distinction to the breadfruit and other fruit trees of the Pacific

islands. One fact of interest is the irregularity of distribution of cay plants: Ambrosia hispida is widespread on Sandbore Cay, Lighthouse Reef, and Cay Bokel, Turneffe, but is of minor importance elsewhere; Sesuvium and especially Ipomoea may be entirely absent on some cays. Many of the cay plants have seeds viable after long immersion in salt water, notably Tournefortia, which can germinate after six months (Sauer, 1959, 9).

Attempts have been made to relate the present distribution of plant associations on cays to stages in the development of vegetation on new cays: that the bare sand is first colonised by a strand association (Sesuvium, Ipomoea), which ultimately develops into tall interior thicket (David, 1942, 126-131; Chapman, 1944). The succession in space is also a succession in time. If this is to have value it requires detailed work by trained botanists and in this connection it should be noted that the maps showing vegetation distribution on the cays are intended to show gross features of the vegetation only. Strand vegetation alone is recorded in any detail. No previous collections have been made from these cays, so that the list of plants collected (Appendix 2) will probably be much extended. I am very grateful to Dr. F.R. Fosberg for the identifications, and much advice on botanical matters.

Marine algae and other plants have been noted in some of the detailed cay accounts. Algae were collected and the identifications are awaited. For an account of some algae from the barrier reef, see William Randolph Taylor (1935).

B. The mangrove cays

In addition to sand cays, Vermeer described two other types from British Honduras: "mangrove cays", consisting of clumps of Rhizophora mangle, which he noted from the barrier reef lagoon and Turneffe, and "mangrove-sand cays", which he described only from the barrier reef lagoon (Vermeer, 1959, 32-40). Both these types are found on Turneffe, the mangrove-sand cay is also found on Lighthouse Reef, and they are absent only from Glover's Reef.

The mangrove cay

Little information is available on mangrove cays, partly because of the difficulties of studying and mapping them. They are frequently large and cover a much greater area than the sand cays; they have little or no dry land, consist wholly or predominantly of Rhizophora mangle, and have little wild life apart from birds and boa constrictors. As Vermeer notes, one of the closest approaches in the literature to the British Honduras type of mangrove cay is in the Bogue Islands of Jamaica, described by Steers (1940a), which I was able to see from the shore in 1960. On the atolls, simple mangrove cays are confined to Turneffe, where they often rise from fairly deep water, suggesting some kind of basement. The completeness of the canopy and stilt and drop roots give a unique and disconcerting atmosphere to this type of cay.

It has often been loosely stated that mangrove colonisation leads to growth of land areas, but it can be seen that mangroves can only take root in shallow water (Vann, 1959, 359-360). A drying shoal is not necessary, for Rhizophora seedlings can grow in 2-3 inches of water; they are found on varied substrates, from coarse shingle to sand, but are most numerous on sheltered shores of medium-fine sand. Where a mangrove cay rises from water deeper than 1-2 fathoms, then some kind of basement must underlie it: such as a sand bank or coral patch-reef. Once Rhizophora is established on such a shoal, however, there is little doubt that its intricate root system will serve to trap further sediment and raise the floor level, partly at least because of humus accumulation and the formation of peaty mangrove soil (David, 1940, 325-327; Newell and others, 1959, 224-225). Mangrove may even be a fine-sediment producer by aiding chemical erosion of reef rock on which it stands (Wharton, 1883; Fairbridge, 1950, 334).

As the floor level rises, ecologic conditions change, and there is a fairly well documented transition from pioneer Rhizophora, through Avicennia, to Conocarpus bush, and finally to dry land thicket and forest (Richards, 1953; Davis, 1940). This leads to an ideal succession in time at any one point, and to a succession in space at any particular time. In British Honduras, however, one has the impression that Rhizophora is overwhelmingly dominant in the true mangrove cays, and that the general succession is not here established. Rhizophora grows rapidly, and in the case of one barrier reef cay the entire island is known to have developed since 1819; on the other hand, map evidence (which is admittedly liable to error) does not show any great extension of mangrove area on Turneffe since about 1750. This may partly be due to the contemporary rise in sea level of 4 inches per century cancelling out the effect of mangrove sedimentation and retarding the succession. Alternatively, the fact that mangrove cays, especially in the Turneffe lagoons, do not seem to be expanding laterally, may result (a) from limited foundation area, and (b) tidal current scour. It has already been suggested (Section V) that many of these cays may stand on karst-eroded foundations of Glacial age.

Generally the mature Rhizophora of these cays reaches a height of 20-30 feet; the tallest seen, on the east side of Turneffe, reached 40 feet. While young they are liable to be uprooted in hurricanes; no examples were seen on the atolls, but unusually low mangrove cays in parts of the barrier reef lagoon suggest such action.

The mangrove-sand cay

This type of cay was described by Steers in the Bogue Islands, north coast of Jamaica (1940a, 36-37). These are a group of mangrove islands, the innermost with no dry land, the outermost with "low sand areas lying on or near the outside of the mangroves... The lee side shows no land at all." The sand areas here are up to 250 yards long and 20 yards wide, but do not rise more than 18 inches above the sea. Vermeer (1959, 35-40) describes the mangrove-sand cay type from the British Honduras barrier reef lagoon, where he found cays up to 5 miles in length, bounded on their seaward, exposed side by sand ridges 1-200 yards wide and 4-12 feet high; hence on a much larger scale than in the Bogue Islands. From the detailed cay descriptions in Sections V and VI it will be seen that mangrove-sand cays are well-developed on both

Turneffe and Lighthouse Reef. Indeed, one might say that Turneffe is really one large mangrove-sand cay, in view of the extensive sand ridge on the eastern side of the main lagoon mangrove mass. On Lighthouse Reef, Northern Cay and Long Cay are examples: both have extensive sand areas on their northern sides, and Long Cay has a long, low narrow sand ridge along its eastern, reef-facing shore.

Mangrove-sand cays include four main vegetation zones: (a) the strand vegetation of the seaward sandy shore; which is comparable to similar strand areas on sand cays, except that shingle-loving plants such as _Tournefortia_ are unimportant; (b) the sand-area thicket of palms, _Conocarpus_, _Suriana_, _Coccoloba_, and other trees and bushes, with an undercarpet of _Hymenocallis_, _Wedelia_, _Stachytarpheta_, _Andropogon_, _Cyperus_, _Eragrostis_; (c) the mangrove-transition zone, with _Conocarpus_, _Avicennia_, _Laguncularia_, and some tall ancient _Rhizophora_; and (d) the _Rhizophora_ zone, often "hollow", with much standing water and dead and dying trees, fringed with vigorous, bushy mangrove. On both the atolls today the vegetation of the sand areas of the mangrove-sand cays has been largely cleared for _cocal_, and the vegetation boundary between sand and mangrove areas is now unnaturally abrupt. Beachrock forms along the sandy shores, exactly as on true sand cays, and the main difference between the two is that shingle is generally absent from mangrove-sand cay shores on account of their distance from the reefs.

Origin of the mangrove-sand cays

Vermeer explained the three cay types (sand, mangrove-sand, and mangrove) of the barrier reef lagoon as resulting from differing degrees of exposure to wind and waves. "Thus, in going from the main barrier reef to the (mainland) shore one might expect to encounter, in succession, sand, mangrove-sand and mangrove cays" (1959, 39-40). This is attractively simple, and undoubtedly contains much of the truth; but in the case of the barrier reef it depends largely on the shallowness of the lagoon floor back of the barrier, and where deeper water is found quite a different zonation results. Further, mangrove cays may occur in very exposed locations (Pelican Cay, Turneffe; Columbus and other cays, barrier reef), suggesting that degree of exposure, or proximity to the reef, is _in itself_ not a sufficient explanation.

The only other area in which detailed botanical work on mangrove-sand cays has been carried out is in the Marquesas Group, off southern Florida, studied by J.H. Davis. Here cays are found with inner mangrove zones, and outer sea-facing sand ridges. In the adjacent Dry Tortugas, few or no mangroves are found, and only sand cays occur (Davis, 1942, 131-133), in spite of the fact that "seeds and seedlings of all three (mangrove) species float there by the thousand" (134). This Davis explains primarily by the fact that "at the Marquesas there are no coral reefs, but at the Tortugas living coral reefs abound" (122); hence sediments at the Marquesas are finer than at the Tortugas. In an earlier paper, he pointed out that mangroves grow better on marl muds than on coarse calcareous sands and shingles (Davis, 1940, 358). These conclusions can be applied to the mangrove and mangrove-sand cays of British Honduras (Stoddart, 1962): the presence of mangrove is related largely to the grain size of the debris supply, which depends both on exposure

and on the source of the debris. Mangroves are least common on exposed coral reefs, where there is a constant supply of coarse debris; they take hold either on sheltered coral reefs, or on lagoon sand shoals, where the debris is fine sand or even mud, and coarse material is uncommon. Whenever coral reefs are found close to mangrove islands in fairly exposed locations, then sand and even shingle ridges will be formed (exposure in this sense includes not only distance from the reefs and absence of intervening islands, but depth of water offshore). This explains the formation of the low wooded islands of the Great Barrier Reefs, with their distinctive association of shingle ridges, mangrove and sand cays on one reef patch (Spender, 1930); the very similar cays described from the Java coast by Umbgrove (1928, 1930); and the precisely analagous islands, unnoticed by Vermeer, from the British Honduras barrier reef lagoon, which I hope to describe shortly. The size of the debris determines the effect, on cays, of exposure, in the broadest sense. This suggests a general principle, of world-wide application to all types of cays--mangrove, mangrove-sand, sand, shingle, and low wooded islands.

The mode of development of the mangrove-sand cays off British Honduras, in the Marquesas and Bogue Islands, is largely unknown. Vermeer (1959, 116) considers that this type of cay "appears first to have been formed as a sand cay and subsequently colonised by mangrove seedlings on the leeward side". I doubt whether this is the case, for if so we might reasonably expect to find embryonic mangrove-sand cays not yet colonised by mangrove: in other words, sand cays lacking all the characteristics of form and location of true sand cays. Such islands are not found, and one doubts whether the sand ridge itself could accumulate without the obstructive effect of the mangrove. This is in fact suggested by the Bogue Islands. The two sections probably originate and develop as a single unit, rather than form sequentially.

Finally, the largest problem of all: why are the mangrove cays so extensive on Turneffe and Lighthouse Reef, and absent on Glover's Reef? This appears fundamentally a question of levels. Turneffe owes its mangrove to its highstanding, shallow upper surface, perhaps developed by karst erosion in Glacial times to give the lagoon-rim form (Section IX). There is evidence of recent local warping which would locally expand the shoal area and lead to further mangrove colonisation. On Lighthouse Reef there is evidence of local uplift of the entire bank of not more than 2 feet: again, this would cause shoaling of the lagoons and increase the possibility of mangrove growth. On the barrier reef and on Glover's Reef there is little or no suggestion of any similar movement, and here, respectively, mangrove-cays differ significantly in their distribution, or are absent.

C. Conclusion

In this review the probable origin of the atoll cays has been outlined, and the problems connected with them stressed. Many comparisons have had to be made with the barrier reef cays, on which work is progressing, and when this is complete, it is hoped to combine both accounts, compare them with cays described from the Caribbean, Indonesia and

Australia, and outline a general theory of cay formation. Most previous descriptions of cays have been from barrier reef or patch reef areas, rather than from atolls: many Indian and Pacific Ocean atolls have islands which include much elevated solid rock, and are thus rather dissimilar to the cays discussed here. These reef-islands form a study in themselves, quite distinct from that of uncemented cays. Some of the suggestions made in this section (for example, the influence on cays of rising sea-level) are at present rather speculative, and more experimental and field studies are needed to qualify them. To take one problem: are we justified in assuming (as the evidence suggests) that cay retreat is everywhere at present in operation, and in looking for a general cause; or have we misread the evidence, and are cays in fact cyclic structures, forming, eroding, reforming continually, under essentially static long-term conditions, rather like the evolution of multiple shingle ramparts as shown by Fairbridge and Teichert (1947)? This is one question--there are many others--of the utmost importance; and no simple answers are in sight.

Spender defined a sand cay, in an oft-quoted phrase, as "a perfect equilibrium structure due to the drift over the reef flat, the wave system of the lee of the reef, and the height of the flat. For that reason, cays tell nothing of the past history of the reef but only of the actual momentary level of the reef" (1937, 141). This may apply to simple sandbores, but not to large vegetated islands of the type found on these Caribbean reefs and atolls, which are both more complex and more interesting than Spender's summary might suggest. An extension of cay studies throughout the Caribbean area, especially along the west coast of Central America, would add immeasurably to our knowledge in a completely unknown area.

IX. ORIGIN AND DEVELOPMENT OF THE BRITISH HONDURAS ATOLLS

Though this paper chiefly described the results of a reconnaissance of the British Honduras atolls, and is mainly concerned with their present condition, some brief remarks may be made in conclusion on their development towards their present form. As stated in Section II, the reefs appear to be built on fault-controlled ridges and platforms, bounded eastwards by steep slopes carrying the sea floor down to depths of over 10,000 feet. The faulting is associated with the evolution of the Bartlett Trough, the main movements of which were of Pliocene date, and thus the reef foundations probably came into being in late Tertiary times. No solid rock outcrops on the atolls, and no drilling has been carried out, so it can only be suggested that the fault-bounded platforms may consist of Cretaceous and Tertiary limestones overlying Palaeozoic rocks, as they do on the adjacent coastlands. The three atolls rise 900-1,000 feet from the platforms on which they stand. Making maximum allowance for Pleistocene fluctuations of sea-level, this is several hundred feet deeper than reef-building corals can grow (Stearns, 1946, 261). If the foundation of the atolls below about 450 feet can be shown, by boring or seismic work, to consist of reef-building corals and their debris, then subsidence of the fault-blocks and upgrowth of reefs from them is indicated (Darwin, 1842). The alternative, implied by Ower (1928), is that the foundations of the atolls, below the maximum depth of reef-building corals, consist of isolated fault-blocks of limestones or Palaeozoics, delimited by faults transverse to the main lineations. The only evidence for such faults lies in the existence of the reefs themselves; and thus this fundamental question remains unsettle.

Pleistocene events

The subsequent course of events is by no means clear, but it is possible that reef-building corals became established on the Platforms before the onset of Pleistocene glaciation; indeed, it is possible that they had built a reef several hundred feet in thickness in late Tertiary times. Certainly when glaciation began the banks stood at or near their present level: Turneffe with its upper surface 2-3 fathoms below present sea-level, Lighthouse Reef 2-4 fathoms, and Glover's Reef 15-24 fathoms; or rather lower, allowing for subsequent reef-growth and sedimentation. The onset of glaciation brought, as Tylor first recognised in a long-neglected statement (1868, 1869, 18, 72), and as Daly subsequently stressed (1910 and later), multiple falling of sea-level coinciding with each separate advance of the continental glaciers. This would have the two-fold effect of killing all near-surface reefs by the mere fact of exposure, irrespective of temperature change, and of exposing the summits of the banks, a mass of reef and lagoonal limestones, to subaerial erosion. The question as to whether corals could survive during the glacial periods--whether the atolls are located in Davis's coral seas or marginal belts (Davis, 1923, 1928)--is thus, on such steep-sided blocks, somewhat academic. Palaeotemperature curves published by Emiliani (1955), based on isotope ratios of near-surface Foraminifera in

two Caribbean deep-sea cores, suggest that over the last 280,000 years, near-surface sea temperatures in the Caribbean have undergone fluctuations of not more than 6°C. Even a fall of this amount in the winter surface temperatures recorded at Rendezvous Cay would not extinguish the reefs, though the species-composition might be radically changed and the reefs attenuated.

The major effect of glaciation would, however, be the sea-level fall. Daly estimated this at a maximum of 33-38 fathoms (1915, 174), Stearns at 45 fathoms (1946, 261) (200-230 and 270 feet respectively). Charlesworth in a recent review gives figures of 93 metres (300 feet) for the last glaciation and 120-130 metres (400-430 feet) for maximum glaciation (Charlesworth, 1957, II, 1354-1355). Such a fall would expose the whole of the British Honduras coastal shelf, lead to deep incision of river valleys now filled with alluvium (e.g. North Stann Creek: Dixon, 1956, 29), and to the extension of drainage lines across the emerged area. It is thought that the Belize Deep-Water Channel, meandering across the coastal shelf and cutting through the barrier reef, with depths of up to 190 feet, is such a drainage line, though why it should pursue this course, and why it should cut so great a trench, is unknown. At the same time the coastal shelf reefs and the summits of the outer banks, would be exposed to karst erosion. Hoffmeister and Ladd (1945) showed experimentally that under erosion a limestone block tended to develop an irregular concave surface, and MacNeil (1954) used this as the basis for a theory of atoll development on subaerially preformed foundations. Such a process may well have resulted in the present form of Turneffe, where a mangrove covered rim surrounds a deeper, extensive lagoon area (fig. 49). In this case the present reefs are superficial additions to the edges of the atoll-like bank, rather than its essential cause.

Glover's Reef (fig. 49) is somewhat different, for here the lagoon floor descends to depths of over 140 feet, and averages 90-120 feet. This is still well above the presumed low limit of the glacial seas, and must have been subjected to karst erosion. On Lighthouse Reef (fig. 49) the general lagoon floor level is only 20-25 feet below present sea-level, and would be similarly affected: the Blue Hole provides evidence of karst erosion down to 480 feet. Workers on the Gulf Coast of the United States envisage a glacial low limit of about 450 feet (Le Blanc and Bernard, 1954). Why such features as the Blue Hole are not much more numerous is not clear. Dimpling of the Lighthouse lagoon floor on a much smaller scale than the Blue Hole, and some of the deep passages and holes on the Barrier Reef, may be ascribed to subaerial erosion, but evidence is lacking from Turneffe and Glover's Reef at present.

Karst erosion certainly continued therefore during glacial low sea-levels, and may have resulted in the basining of the tops of the banks and the creation of a rudimentary atoll form, though this was probably already in existence. Daly (1910 and later) stressed low-level benching of islands and banks by the glacial seas, but the absence of such benches in British Honduras lends support to Newell's view (1960)

that such benching was of small effect. There is no evidence from the atolls of deep abrasion platforms, while on the coastal shelf the barrier reef edges a tilted antecedent platform of probably pre-glacial age, in whose formation it played no part, much as Vaughan supposed (1916, 1919a).

Not in Bib

Daly recognised (1919) that reefs might become re-established during inter-glacial high sea-levels, and there is some evidence of major reef upgrowth of either pre- or inter-glacial age on both the barrier reef and Glover's Reef. The evidence is entirely physiographic. On the barrier reef, the present reef-flat rises from a broad platform 3-4 miles wide in the north and 2-4 fathoms deep. Farther south, where the surface reef becomes fragmented, the "lower flat", as it may be termed, becomes narrower (averaging 1 mile in width), but maintains its depth for over 100 miles. Its surface is irregular and in places deeply pitted, suggestive of erosion; it rises steeply on the lagoonward side from the lagoon floor, and is edged on the seaward side by the present "upper" reef-flat and reef. Serial sections across the coastal shelf and barrier reef show the remarkable persistence and regularity of this feature. It was shown in Section VII that a similar "low platform" is found at a depth of 4 fathoms surrounding the Glover's Reef lagoon; this too is rimmed on its seaward side by the present reef-flat and living reef. It might also be noted that the Lighthouse Reef lagoon floor lies at or a little above the level of this "lower platform".

This feature is clearly not related in origin to the present, post-Würm living reefs, which date entirely from the last rise of the sea. Dr. E.G. Purdy informs me that a peat from the Belize Deep-Water Channel at 70 feet in depth has been dated at 8,000 years BP, which narrowly circumscribes the age of present living reefs. It is unlikely that the lower platform results from the subaerial erosion described by MacNeil, on account of its width, horizontality and extent, and one is led to the conclusion that it can only be an old reef surface, developed during a much longer period of time than present living reefs. Much of the evidence for this rests on data from the barrier reef which cannot be discussed here, but the conclusions must also be valid for the atolls. Whether the surface is one of upgrowth or degradation is another matter: its surface on the coastal shelf is irregular and pitted, and was probably much eroded during exposure. It is intersected by the Belize Deep-Water Channel and a few other gaps. Work carried out by Dr. B.W. Logan on Campeche Bank (personal communication, 1961) suggests that a similar level cannot be traced north of the Yucatan Peninsula. He finds marked eustatic benches at 50-55 fathoms (correlated with the Wisconsin glaciation), 30-35 fathoms, and 16-20 fathoms; and suggests that a level at 2-4 fathoms might be related to the lower depth limit of <u>Acropora palmata</u> reefs. He describes such a constructional bench on the Campeche Bank at depths varying from 30 feet in windward locations to 10-15 feet to leeward. It seems unlikely, however, that this can be applied as a general explanation for a feature of such size as the British Honduras "lower reef-flat". The absence of such a level on Campeche Bank throws some doubt on its eustatic origin; yet its horizontality over a large area suggests that foundering cannot account for its present low level. Whatever its origin, this bench is of the greatest importance in the physiography of the British Honduras reefs, for on it all the present

surface reefs are built, and its presence at Glover's Reef shows that the atoll-form was already established when it was built. Benches underlying modern reefs have been described from Bikini (15-50 feet deep: Tracey, Ladd and Hoffmeister, 1948; Emery, Tracey and Ladd, 1954, 26ff.), from Raroia (edges at 25 and 65 feet: Newell, 1956, 334, 341), and Andros Islands, Bahamas (an inner platform at 2 fathoms separated by a line of oolite cays from an outer platform at 2-16 fathoms: Newell and others, 1951, 10, 24); but there seems little point in attempting to correlate these with benches in British Honduras.

The lower levels described as eustatic by Logan cannot be identified in British Honduras; they probably exist as unconformities within the reef-mass, and have been buried by later growth and sedimentation. They have also been described from the Gulf Coast by Shepard and others (1960), and the 16-20 fathom level in particular seems widespread in the Caribbean basin. Zans (1958, 7) describes it from the Pedro Bank, and examination of charts shows widespread occurrence of levels of from 11 to 23 fathoms on at least 13 banks in this area (Admiralty charts 450, 486 and 762). Stillstands of the sea at such levels, connected with glacial eustatism, have undoubtedly been important incidents in the growth of present reefs.

The emphasis in reef-growth is thus placed on glacial control of fluctuating sea-levels, though this does not preclude earlier subsidence on the Darwinian model. Whether or not subsidence has taken place is, in view of these fluctuations, irrelevant insofar as present surface form and features of the reefs is concerned (MacNeil, 1954). Darwin himself thought subsidence an unlikely explanation for these atolls, basing his opinion on Captain Allen's reports of Owen's survey. He doubted that both the barrier reef and its lagoon floor were built by reef-corals, thinking rather of an accumulation of sand similar to that which he thought was taking place on the Nicaraguan and Yucatan banks. On the atolls he wrote:

> "....immediately on the outside of this barrier-like reef, _Turneffe_, _Lighthouse_ and _Glover_ Reefs are situated, and these reefs have so completely the form of atolls, that if they had occurred in the Pacific, I should not have hesitated about colouring them blue. _Turneffe Reef_ seems almost entirely filled up with low mud islets; and the depth within the other two reefs is only from one to three fathoms. From this circumstance, and from their similarity in from, structure, and relative position, both to the bank called _Northern Triangles_, on which there is an islet between seventy and eighty feet, and to _Cozumel_ Island, the level surface of which is likewise between 70 and 80 feet in height, I consider it more probable that the three foregoing banks are the worn-down bases of upheaved shoals, fringed with corals, than that they are true atolls, wholly produced by the growth of coral during subsidence...." (Darwin, 1842, 202).

Thus Darwin's view is comparable with that adopted here, though for rather different reasons; his undogmatic approach is still instructive.

Post-glacial history

With the rise of sea-level in the last few thousand years, reefs grew to the surface and expanded seawards, leaving a shallow sandy reef-flat averaging 1 mile in width. Cays were formed on this flat from reef-debris, and vegetated, and beachrock formed around their margins (Section VIII). The evidence taken from British Honduras as a whole seems to indicate that sea-level has not at any time since the last glaciation stood considerably higher than at present—a view taken by many workers on the Gulf Coast (Le Blanc and Bernard, 1954; Shepard and others, 1960). On the other hand, work in the Pacific seems to indicate a recent higher stillstand of the sea, as summarised by Tayama (1952, 271):

> "The so-called sea level Coral Reefs are not of Recent origin. The Sea Level Coral Reefs have been generally accepted as recent, but most of the present reef-flats are abrasion surfaces, like pavements, displaying cross-sections of truncated reef-building corals, benches and mushroom rocks. The so-called Recent Coral Reefs are relicts of coral reefs of corals of the age of the Younger Raised Coral Reef Limestone. As Dr. H. Yabe has stated, the coral reefs, in the recent seas, are in process of destruction rather than of construction. The scope of the destruction, however, is limited to an area approximately 2 metres above low tide."

Stearns so interpreted the reef-flats of Eniwetok Atoll, Marshall Islands and other Pacific areas (1945a, 1945b, 1946) (cf. Ladd and Tracey, 1949, 300, and Emery, Tracey and Ladd, 1954, 92), and Cloud, following work on Onotoa, saw in this supposed fall from a 6 foot stillstand a general explanation for the appearnce of existing reefs (1952, 1954). On the characteristics of a reef-flat developed by downwearing of an earlier, higher surface, he wrote: "If it is sparse in living coral and veneered with green algae and clastic debris, and particularly if it is also a relatively smooth surface, it was probably truncated" (1952, 54). These characteristics, taken by themselves, hardly seem an adequate foundation for a conclusion of such importance. More positive evidence of emergence is needed, such as areas of dry reef-rock and mushroom rocks, shallow rock-floored reef-flats, raised beachrock, raised beaches and abnormally high cays, all found <u>consistently over wide areas</u> and developed on diverse structural units.

Vermeer (1959), however, considered that there is sufficient evidence of a 6 foot high stillstand on the British Honduras reefs to justify correlation with the Pacific 6 foot bench. His evidence for this is threefold: (a) Vermeer described raised beaches from two cays, Ambergris Cay, barrier reef, and Long Cay, Lighthouse Reef. Both were visited in 1961, and no evidence was found to establish this view. These he correlated with the Harry Jones raised beachrock, Turneffe, figured in Dixon's (1956) report as 7 feet above sea-level—a misprint, since the beachrock does not rise more than 2 feet above the sea at any point. (b) He considers that the reef-flat of the central barrier reef is abnormally wide and shallow, and that it must therefore be an erosional surface. (c) He correlates these instances with nearby areas, especially in Quintana Roo, where similar instances are said to have been found.

Vermeer's conclusion is thought to be erroneous, for the following reasons. The raised beaches which form the basis of the theory are not established, and no trace of similar beaches has been found on any of the 70 cays mapped in detail on the British Honduras reefs since 1959. Regarding the reef-flats, nowhere on the British Honduras reefs do we find a single erosional mushroom rock or exposed eroded reef above present sea-level: with the exceptions only of the patches on the windward reef of Lighthouse Reef, and the dry reef at Soldier Cay, Turneffe. Beachrock remnants at Half Moon Cay, Lighthouse Reef, stand 12-18 inches above mean sea-level, and extensive remnants at Northern Cay on the same atoll at similar elevations, taken together with the patches of drying reef-rock, suggest that the atoll as a whole has undergone a recent positive uplift in recent times, but that this has not been greater than about 2 feet. On Turneffe, the restriction of drying reef to a single area at Soldier Cay, and the fact that it lies only a few hundred yards from the Harry Jones raised beachrock, thought, on account of its lateral dip, to be tectonic in origin, suggests that here too is evidence of local uplift, rather than of eustatic shifts of sea-level. Height-equivalence alone is an insufficient ground for correlation of evidence in support of the eustatic theory, for many other factors relating to each item of evidence must be considered. Local differential movement, resulting from crustal instability, is only to be expected on the margins of a tectonically active area such as the Bartlett Trough--witness upraised reef limestones of recent age in Cuba, Haiti and Jamaica. To accept the eustatic theory of a 6 foot fall in sea-level, we must first explain the total absence of erosional mushroom rocks and similar evidences on the reefs; Vermeer's reference to a so-called "Negro Head" marked on charts of the barrier reef lagoon is misleading, for the name simply applies to a small mangrove island south of Middle Long Cay, and does not have any wider implication. Furthermore, all the cays at present found are referable to present sea-levels (Section VIII), none being so abnormally high that they must have developed in such a high stillstand. Detailed surveys are of assistance here, for without instrumental levelling on a number of cays as standard, one consistently overestimates their heights by as much as 30-40%. Most of the more protected cays are less than 4 feet above the sea, and very few indeed rise more than 8 feet. Thus, after a fall of sea-level of 6 feet to the present level, only very restricted small areas could possibly be referred to the earlier stillstand. Kuenen (1933, 1950) and many others (Gardiner, 1903-6, 1931; Sewell, 1935, 464-479) have considered reef islands to be relicts exposed by such a fall of sea-level, and some have gone so far as to argue that without such a fall very little or even no land at all would exist on the reefs. Since so very little of the land of the British Honduras cays can possibly have existed above a 6 foot sea-level, this is not thought to apply to these reefs to more than a very limited extent, which has been discussed in Section VIII.

Finally, we may briefly examine the instances which Vermeer correlates with his supposed 6 foot stillstand in nearby areas. First he mentions elevated reefs in northern British Honduras (Romney and others, 1959). Flores (1952) briefly mentions these and considers them "Mio-Pleistocene" in age, which would make them very considerably older than the sea-level stand to which Vermeer thinks they have developed

(Fairbridge terms the 6 foot stillstand the "Abrolhos Submergence" and dates it at only 2600-2100 years BP (Fairbridge, 1958, 479; 1961, 147)). Dixon, too, doubts whether these exposures have any relation to exposures on the offshore cays at the present time (personal communication, 1961). Vermeer also refers to elevated coral found by Edwards (1957) on the Quintana Roo coast. Very little information is available on these exposures, and they may be equivalent to those of northern British Honduras. There seems little basis for Edwards's statement (1957, 22) that on Chinchorro Bank "coral reefs....occur above their level of formation" (See Appendix 3).

While dismissing therefore the idea of a 6 foot eustatic stillstand (and a fortiori the numerous other high stillstands of post-glacial time listed by Fairbridge (1961)) because of lack of evidence, there remains the possibility of minor fluctuations of sea level affecting the area as a whole. These have been discussed in another paper (Stoddart, 1962), and the evidence consists largely of physiographic features of the cays and drowned beachrock. The difficulties of such an interpretation are there stressed, and the tentative conclusion reached that undercutting of cay margins and the migration of cays away from reef edges may indicate a slight negative shift of sea level, as envisaged by Kuenen (1933); and that drowning of relict beachrock and intensification of cay erosion has resulted from a subsequent small rise of sea-level (Fairbridge, 1947), perhaps associated with the recent shrinkage of glaciers (Ahlmann, 1949). These changes are on a very much smaller scale than anything required by the 6 foot and higher stillstands. Kaye (1959) has stressed the difficulties of precision in determining levels and changes of levels, especially in short visits to cays; he considers it doubtful whether measurements can be accurate to more than ± 1 foot, and doubtful whether sea-level shifts of less amplitude than ± 2 feet can be detected in rapid surveys (though Newell has claimed to identify relative movement of only 15-20 cms (much less than a foot) at Raroia (1956, 334)). The writer would agree with Kaye's opinion, even at the risk of excessive caution. It is possible that all these effects may result from a slowly rising sea-level, and that erosion has been initiated without any fall of sea-level at all.

These conclusions may well be upset by future detailed work, particularly on the British Honduras coast and the infill of the deeper valleys, but even if fluctuations are found there and can be dated, the problem of correlation with the reefs and cays is immense, as Australian experience shows (Steers, 1929, 1931, 1937). Conversely, if these conclusions are shown to be correct, then Cloud's views on the origin of surface reef features (1953, 1954) do not have universal application, and some reefs at least have not been affected by a recent fall in sea-level, but results from "an essentially static position of sea level during a considerable period" (McKee, 1959, 243).

Classification of the reefs: some considerations

In a previous paper (Stoddart, 1960), the three reefs considered here were termed the "outer bank reefs", while in the present paper they are termed atolls. It is fitting in conclusion to consider briefly the validity of this term as applied to these reefs, and to suggest its limitations.

Since the time of Chamisso, the atoll has been recognised as "a mass of rock, which rises with perpendicular walls from the unfathomable depth of the ocean, and forms on the surface an overflowed plateau. A broad dam, constructed by nature round the edge of this plateau, changes it into a basin" (Chamisso, in Kotzebue, 1821, III, 140; see 140-159, 331-336). Darwin (1839, 1842) subsequently elaborated on this picture, but went further and tended to exclude from the atoll-class atoll-like reefs not clearly formed by subsidence (exemplified by his treatment of the British Honduran reefs quoted above). Yet even so thoroughgoing a Darwinian as Davis was compelled to admit that atolls are "inscrutable structures" (1928, 14), and that the definition of an atoll must depend upon its surface features rather than inferred or even demonstrated origin. Thus the fundamental question of what constitutes an atoll revolves round certain observable phenomena. Thus Cloud (1957, 1009) states that "atolls consist of ringlike organic reefs that surround lagoons in which there is no pre-existing land. The ring-reef, the lagoon, and the absence of pre-existing land are all essential features." This definition differs in one important respect from Chamisso's, for Chamisso adds (with a certain poetic license) that atolls rise "with perpendicular walls from the unfathomable depth of the ocean." This criterion is of some importance, for by accepting it we exclude reefs rising from shallow shelves with poorly developed reef-rims, having only a superficial surface resemblance to true deep-sea atolls. Thus, in the Caribbean, Glover's and Lighthouse Reefs would qualify as atolls, Alacran Reef would not. In my view there are not sufficient similarities between these reefs to classify them all as atolls, if the term is to retain its usefulness. Any definition must, therefore, include (1) the fact that reefs rise from depths greater than the depth at which reef-building corals can grow, which, taking glacial low sea-levels into account, may be placed at 75 fathoms; (2) that they possess a well-developed reef-rim and reef-flat, which for example, Glover's does and Alacran does not; and (3) that the reefs contain a lagoon.

Further refinement is needed in the matter of lagoon depths, whose variability has been recognised since Darwin's time. Daly (1915), Yabe and Tayama (1937) and Tayama (1952) have subsequently traced relationships between lagoon depths and the size of the atoll. Cloud (1957, 1013) recognises that "atolls may thus grade to table reefs with emergence or filling of the lagoon", citing Washington Island as an example of an atoll with "a very shallow brackish pond instead of a lagoon." Since table reefs (Tayama, 1935) will normally have more vigorous coral growth on their edges than in their centres, the question arises as to what depths a lagoon must have before a table reef becomes an atoll. Tayama attempts to deal with this difficulty by erecting the intermediate class of "Almost Table Reef" (1952, 221, 258-9), with small lagoons "generally less than 5 metres deep, but a depth of 20 metres is recorded" (258). Table reefs in his view are small and have no lagoon. For true atolls, Tayama found that in the South Seas the "shallowest record of all the lagoons is 9 metres" (1952, 247), or $4\frac{1}{2}$ fathoms. Clearly no general depth can be proposed at which an atoll ceases to be an atoll and becomes a table reef. One simple criterion may be proposed: if a definite lagoon exists, i.e. if there is a marked and recognisable

break of slope between the peripheral reef-flats and the interior part of the bank, and other conditions are satisfied, then the name atoll is justified; and if not, not. If there is no well-marked reef-flat, then the bank is a table reef rather than an atoll.

What of the application of these criteria to the British Honduras reefs? Glover's Reef emerges as a splendid example of a true atoll, comparable to anything in the Pacific or Indian Oceans: it has Chamisso's "unfathomable ocean" surrounding it, and a beautifully defined reef-rim, with in addition a deep, basin-shaped lagoon. Lighthouse Reef has Chamisso's basic attributes, but the lagoon is shallow--with depths mostly less than Tayama's shallowest South Seas atoll. Nevertheless, because there is a well-marked break of slope between the peripheral reef-flats and the interior of the bank, which lies deeper than the reef-flats, it must be a true atoll, though rapidly becoming marginal to this class through reef-upgrowth and sedimentation.

Turneffe has only one of Chamisso's characteristics: it rises from a deep sea floor below the limit of growing coral. Growing reef corals are found in a well-defined belt round the edges of the banks, but do not form a discrete wave-breaking zone round its entire margin, and--more important--only locally fringe a reef-flat. There is thus no evidence that the present living reefs contribute significantly to the <u>form</u> of the Turneffe bank, and further, since there is no reef-flat the lagoon cannot be said to lie below it, and hence the term atoll is inapplicable. In fact the central lagoons are very shallow, and even without the mangrove rim the bank could hardly be termed an atoll except for convenience of discussion. The presence and distribution of the mangroves appear to be almost unique, as nothing quite comparable has been described in the literature; the nearest approach seems to be the Marquesas, off southern Florida, described by J. H. Davis (1942). Of the terms already in existence, only two seem to apply to Turneffe: "hummock reef", proposed by Teichert (1947) for the Houtman's Abrolhos, and "bank reef", Davis's term for reefs "which rise back from the outer margin of rimless shoals" (1928, 19, 29). Teichert's term seems to be restricted to reefs rising from shallow sea floors, and is thus inapplicable to Turneffe, with which Houtman's Abrolhos have little in common. Davis's term seems best suited, if stripped of its marginal-belt connotations and used descriptively. Given an appreciable rise in sea-level, it is quite probable that Turneffe would be rapidly transformed into a true atoll, and it is equally possible that it has passed through a true atoll stage sometime in its history.

The title of this paper is thus seen, in conclusion, to be partially a misnomer. Glover's Reef is a full-fledged atoll, Lighthouse Reef marginally so, while the Turneffe Islands may be termed a "bank reef" or "reef-fringed bank", and is not an atoll at all in the sense here defined. It should in my view be deleted from Bryan's "Checklist of Atolls", while the others remain. If the criteria here used are rigorously applied to atoll-like reefs, then more would probably be deleted, and those that remain possess more unity and common characteristics than before.

FIGURE 49

TURNEFFE ISL

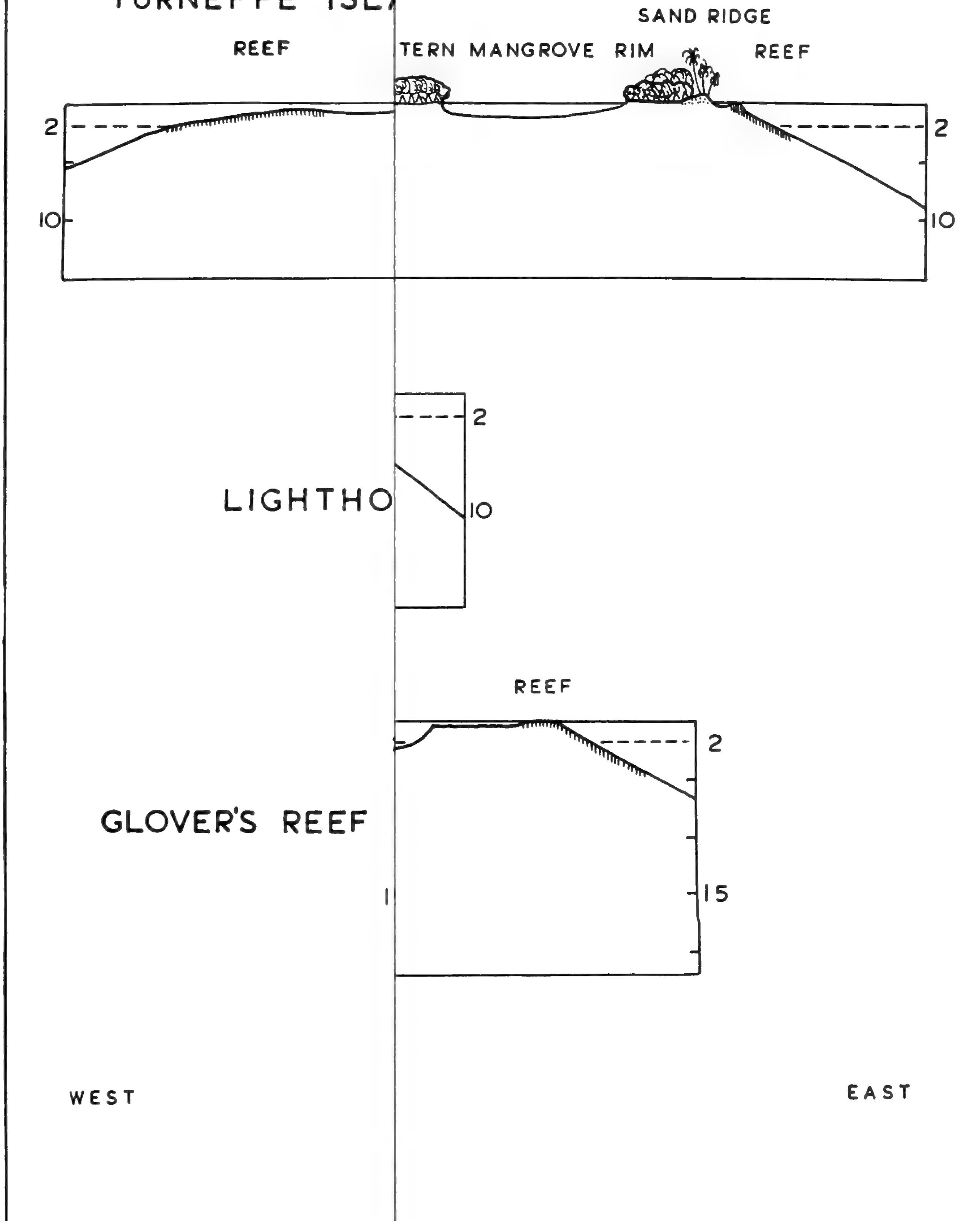
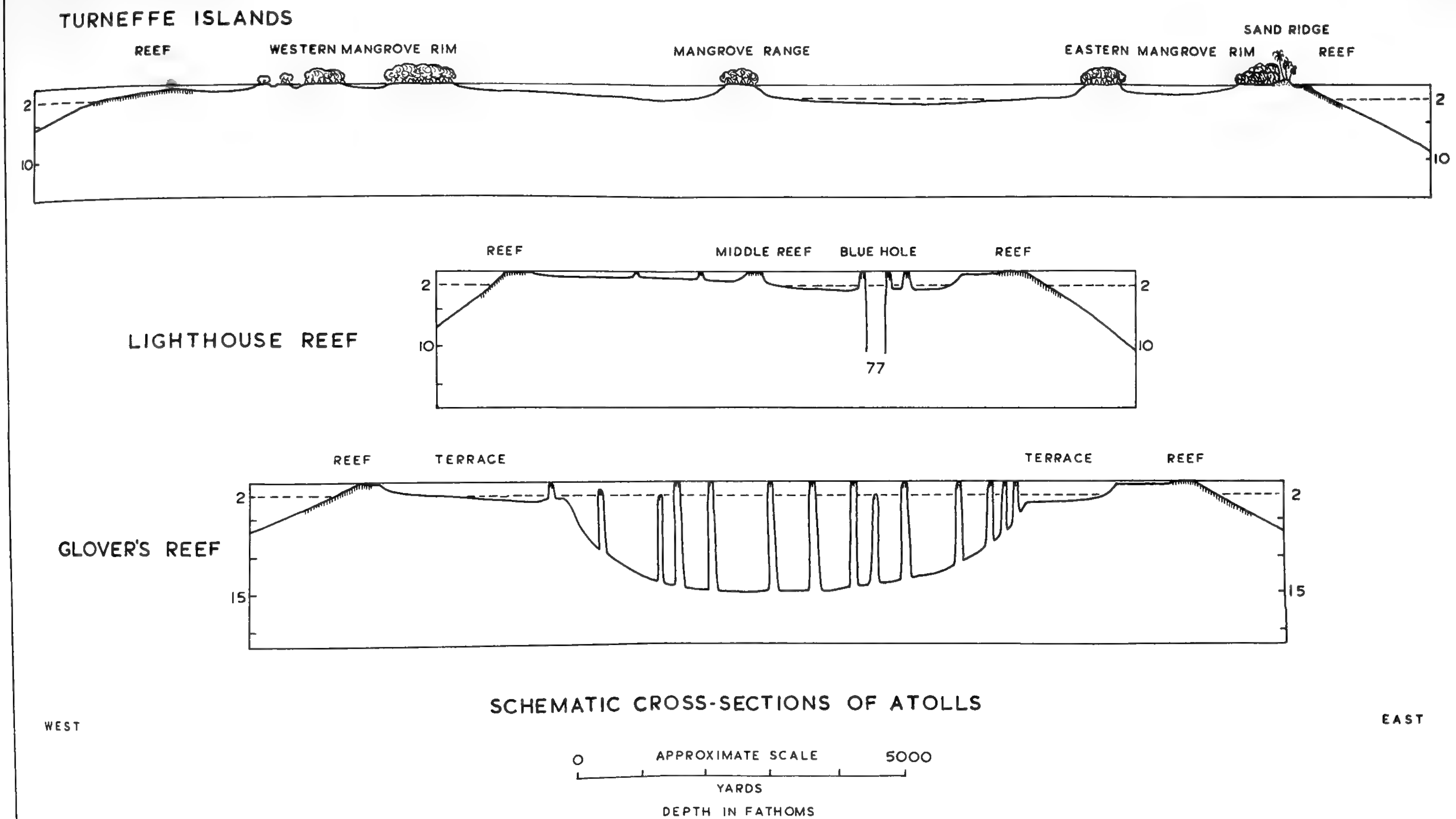


FIGURE 49



SCHEMATIC CROSS-SECTIONS OF ATOLLS

X. APPENDICES

1. Surveying

Problems of surveying sand and mangrove cays have been fully discussed elsewhere--by Lofthouse (1940a, 1940b), Kemp (Steers, 1938, 51-52), Spender (Stephenson and others, 1931), and in the revised edition of Handbook of Atoll Research, edited by Dr. Fosberg and Miss Sachet (1953). Outlines of the cays were mapped by compass traverse and pacing, with surprisingly accurate results. Greatest closure errors were found where beaches consisted of diverse material such as rough coral blocks, or on cays with lighthouses. Maps were as far as possible drawn up immediately. Where topography was considerable, lines of levels were surveyed across the island with a tripod quickset level, and again distances were paced. Details of cay composition and vegetation were booked round the cay margins during the initial traverse, and interior detail later filled in by transects normal to the shore. Speed and accuracy here depends on the recognition of "ecologic field units" of the type listed by Cloud (1952), and increases greatly with experience. Interior detail is least reliable where vegetation is most dense. Mangrove areas present special problems and cannot be surveyed to the same standards as dry land areas. Where mangrove zones on sand cays are less than 100 yards long the traverse was normally carried to seaward of them, but this was liable to disruption by deepening water, softening bottoms, and inquisitive sharks and barracuda. Elsewhere, the traverse was carried to landward, and the exterior sketched in very roughly. Recognition of vegetation units also improves with practice, and is helped by the fact that many plants (Sesuvium, Wedelia, Tournefortia and so on) occur in pure stands, often sharply delimited. Distribution of plants was normally sketched in (with pacing of distances) on completed maps. The cay was located with respect to its reef by intersection of conspicuous points--stranded trees, boulders, etc.

Beachrock mapping has problems of its own. Normally one member swam out (or if sufficiently shallow, paced out) to submerged beachrock exposures, and intersections were taken on him at salient points, by the other member from fixed shore stations. The geologic hammer proved a useful measuring rod for depth, thickness and width of beachrock, data being communicated to the person on shore for booking. Where the beachrock is complicated, it is useful to have a third person in a boat to take verbatim notes from the swimmer, and also to collect specimens.

The Turneffe cays were among the first to be mapped in this investigation, before techniques were worked out and the problems appreciated, so that the detail for certain cays on this atoll is less than one might wish.

It should be noted that the cay maps accompanying this paper are oriented according to compass north, not true north.

2. List of plants collected

The following list of determinations of plant specimens collected on the three atolls was furnished by F. R. Fosberg. Several of the specimens were in rather poor condition, or missing from the collection sent to Fosberg, and the names of these are from a set submitted to the British Museum. These are indicated as determined by W. T. Stearn, of that institution, who also sent suggestions on the nomenclature of several other species. The numbers cited are those of the collector, D. R. Stoddart, in all cases. Several specific names were changed after the stencils of the Bulletin were finished, hence the names used in the report differ from those in this list. In such cases, the synonym used in the report is added in parentheses in this list. The unidentified plant mentioned on p. 47 from Mauger Cay is *Batis maritima*.

Gramineae

Andropogon glomeratus (Walt.) B.S.P.
Lighthouse Reef, Sandbore Cay, no. 553

Eragrostis ciliaris (L.) R. Br.
Lighthouse Reef, Half Moon Cay, no. 547

Eragrostis domingensis (Pers.) Steud.
Glover's Reef, Northeast Cay, no. 62

Paspalum pleostachyum Doell.
Glover's Reef, Northeast Cay, no. 63

Sporobolus virginicus L.
Lighthouse Reef, Half Moon Cay, no. 40

Sporobolus sp.
Lighthouse Reef, Northern Cay, no. 52 (Det. W. T. Stearn)

Cyperaceae

Cyperus ligularis L. (*Cyperus planifolius* L. C. Rich.)
Lighthouse Reef, Half Moon Cay, no. 41
Glover's Reef, Northeast Cay, no. 64

Fimbristylis cymosa R. Br.
Glover's Reef, Middle Cay, no. 80

Palmae

Thrinax parviflora Sw.
Glover's Reef, Northeast Cay, no. 77

Amaryllidaceae

Hymenocallis littoralis (Jacq.) Salisb.
Turneffe, Harry Jones Point, no. 512
Lighthouse Reef, Half Moon Cay, no. 39

Orchidaceae

Brassavola nodosa (L.) Lindl. ?
Glover's Reef, Northeast Cay, no. 65

Batidaceae

Batis maritima L.
Turneffe, Mauger Cay, no. 542

Moraceae

Ficus ovalis (Liebm.) Miq.?
Glover's Reef, Northeast Cay, no. 71

Amaranthaceae

Alternanthera ramosissima (Mart.) Chod.
Lighthouse Reef, Half Moon Cay, nos. 551, 42

Iresine diffusa H. B. K. (Iresine celosia L.)
Turneffe, Harry Jones Point, no. 28
Glover's Reef, Southwest Cay, no. 82

Nyctaginaceae

Neea choriophylla Standl.
Glover's Reef, Northeast Cay, no. 68

Phytolaccaceae

Rivina humilis L.
Half Moon Cay, Lighthouse Reef, nos. 545, 44

Aizoaceae

Sesuvium portulacastrum (L.) L.
Lighthouse Reef, Half Moon Cay, no. 46
" " Hat Cay, no. 57
Glover's Reef, Northeast Cay, no. 75

Portulacaceae

Portulaca oleracea L.
Lighthouse Reef, Hat Cay, no. 56

Lauraceae

Cassytha filiformis L.
Lighthouse Reef, Half Moon Cay, no. 32

Leguminosae

Canavalia rosea (Sw.) D.C.
Lighthouse Reef, Half Moon Cay, no. 59

Sophora tomentosa L.
Glover's Reef, Long Cay, no. 79

Surianaceae

Suriana maritima L.
Lighthouse Reef, Sandbore Cay, no. 541
" " Half Moon Cay, no. 47

Euphorbiaceae

Drypetes brownei Standl.
Lighthouse Reef, Half Moon Cay, no. 60

Euphorbia blodgettii Engelm.
Glover's Reef, Northeast Cay, no. 70
" " Southwest Cay II, no. 84

Euphorbia mesembrianthemifolia Jacq. (Euphorbia buxifolia Lam.)
Lighthouse Reef, Half Moon Cay, nos. 33, 58
Glover's Reef, Northeast Cay, no. 74

Euphorbia trichotoma Kunth
Glover's Reef, Southwest Cay, no. 81

Passifloraceae

Passiflora suberosa L. ?
Glover's Reef, Northeast Cay, no. 66

Combretaceae

Conocarpus erectus L.
Turneffe, Mauger Cay, no. 549
Lighthouse Reef, Sandbore Cay, no. 538
Glover's Reef, Northeast Cay, no. 67

Apocynaceae

Stemodia maritima L.
Lighthouse Reef, Half Moon Cay, no. 49

Convolvulaceae

Ipomoea pes-caprae subsp. brasiliensis (L.) v. Ooststrom
Lighthouse Reef, Half Moon Cay, no. 31 (det. W. T. Stearn)

Ipomoea tuba (Schlecht.) Don
Lighthouse Reef, Half Moon Cay, no. 34 (det. W. T. Stearn)

Ipomoea sp.
Lighthouse Reef, Half Moon Cay, no. 37

Boraginaceae

Cordia sebastena L.
Lighthouse Reef, Half Moon Cay, no. 38
Glover's Reef, Northeast Cay, no. 76

Tournefortia gnaphalodes (L.) R. Br.
Lighthouse Reef, Half Moon Cay, no. 45

Verbenaceae

Avicennia germinans (L.) L.
Lighthouse Reef, Northern Cay, no. 55

Lantana involucrata L.
Lighthouse Reef, Northern Cay, no. 53

Stachytarpheta jamaicensis (L.) Vahl
Lighthouse Reef, Half Moon Cay, no. 35
Glover's Reef, Southwest Cay II, no. 83

Rubiaceae

<u>Erithalis</u> <u>fruticosa</u> L.
Lighthouse Reef, Half Moon Cay, nos. 546, 30
Glover's Reef, Northeast Cay, no. 73

<u>Ernodea</u> <u>littoralis</u> Sw.
Lighthouse Reef, Half Moon Cay, no. 552
" " Northern Cay, no. 51

<u>Hamelia</u> <u>patens</u> Jacq.
Lighthouse Reef, Half Moon Cay, no. 36

Compositae

<u>Ageratum</u> <u>littorale</u> Gray?
Lighthouse Reef, Half Moon Cay, no. 48
Glover's Reef, Long Cay, no. 78

<u>Ageratum</u> <u>maritimum</u> H. B. K.?
Turneffe Is., Mauger Cay, no. 543
Lighthouse Reef, Half Moon Cay, no. 43

<u>Ambrosia</u> <u>hispida</u> Pursh
Lighthouse Reef, Sandbore Cay, nos. 554, 50
Glover's Reef, Northeast Cay, no. 72

<u>Borrichia</u> <u>arborescens</u> (L.) DC.
Lighthouse Reef, Half Moon Cay, no. 548
" " Hat Cay, no. 54

<u>Wedelia</u> <u>trilobata</u> (L.) Hitchc.
Lighthouse Reef, Half Moon Cay, no. 61
Glover's Reef, Northeast Cay, no. 69

3. A Note on Chinchorro Bank Atoll, Mexico

It was planned to visit this atoll also in 1961, but this proved impossible owing to the great expense involved. It appears similar in many respects to the British Honduras atolls farther south; but like them it has never been properly described. This note briefly summarises what is known of it. The atoll is kidney-shaped, 26 miles long and $6\frac{1}{2}$-$9\frac{1}{2}$ miles wide, surrounded on all sides by a steep-to reef, which is best developed on the windward side (West Indies Pilot, I, 1956, 484-486). Chinchorro is the only atoll in this area to have been surveyed in detail, by Commander Barnett in 1839, the chart being published in 1850 and not since revised. The lagoon, like that of Lighthouse Reef, is shallowest on the west side (1-2 fathoms) and deepens eastwards to $2\frac{1}{2}$-4 fathoms. The deeper portion is bisected by a tongue of shoal water (1-$1\frac{1}{2}$ fathoms) extending NNE-SSW, and forming the foundation for Great Cay, rising in the centre of the atoll. The greatest depth found in the lagoon is $4\frac{1}{2}$ fathoms.

There are four cays on the atoll: Cayo Lobos in the south, Great Cay (Cayo Centro or Grande) in the centre; and Cayos Nortes in the north. The cays are described as follows in the West Indies Pilot, I, 1956: "Cayo Lobos (Lat. 18°23'N, Long. 87°22'W) is about 5 feet ($1^{m}5$) high and composed of indurated sand and bleached coral. Cayo Centro (Grande) lies in the middle of the lagoon about $1\frac{1}{2}$ miles from the eastern edge of the reef. It is a low ridge of sand covered with vegetation and palms, the tops of which are from 40 to 50 feet ($12^{m}2$ to $15^{m}2$) high. The centre of the cay is occupied by a salt-water lagoon. Cayo Norte consists of two low narrow cays situated close together about 1 3/4 miles within the northern edge of the bank. They are covered with dense vegetation and the tops of trees on them are from 40 to 50 feet ($12^{m}2$ to $15^{m}2$) high." (p. 485). These observations presumably derive from Barnett's in 1839. The ornithologist Griscom spent three days on Chinchorro in 1926, visiting Cayos Nortes and Cayo Centro. One of the Cayos Nortes is uninhabited, and he described it as a "miniature atoll about 200 yards long, with a somewhat higher beach (than Cayo Centro), and no trees" (1926, 1). Cayo Centro he described at greater length, calling it a"perfect atoll", which somewhat strains the usage of the term. He found it

> "consisting of a narrow ring of sand beach, enclosing a central lagoon with one small outlet. The central lagoon is a mangrove swamp with very little open water, full of herons and crocodiles. The leatherwood is the only plant on the island which could be called a fair-sized tree, the flora of the beach otherwise consisting of scrub palms, sea-grape, and a few other shrubs with fleshy leaves of halophytic West Indian types. The destructive hurricane which visited the coast some ten years ago caused the sea to break over the whole island, killing all the taller trees and probably greatly reducing the resident land-bird population. The island has never been inhabited, and is visited occasionally only by turtle fishermen. The forest of dead trees, their gaunt and twisted arms gleaming white and naked in the tropical sunshine, rises above the scrub, and adds a touch of sadness and desolation to a scene, which is, to say the least, lonely and remote"(1926, 1).

Cayo Centro thus seems comparable to Northern Cay, Lighthouse Reef.

Edwards (1957, 22) considers that, from chart evidence, "coral heads and reefs here occur above their level of formation." He presumably refers to Blandford Ledge and Skylark Ledges at the southern entrance, which have been charted in detail; there is no evidence that they are raised. Allen (1841) described the Chinchorro Reefs as "even with the sea"--a description which he also gave to unraised reefs on Lighthouse and Glover's Reefs. Griscom says that "The outer reefs are nearly half a mile wide in places, and the biggest coral heads are four to six feet below the surface. Inside the reef is a lagoon with a white sand bottom, the water gorgeously coloured and clear" (1926, 1). He does not mention raised reefs. The lagoon itself has many patch reefs.

There are two lights on the atoll: one, 44 feet high, on Cayo Lobos; the other, 52 feet high, on the northern cay of Cayos Nortes. The Cayo Lobos light is said by British Honduran fishermen to have been out of action since Hurricane Janet passed over this area in 1955.

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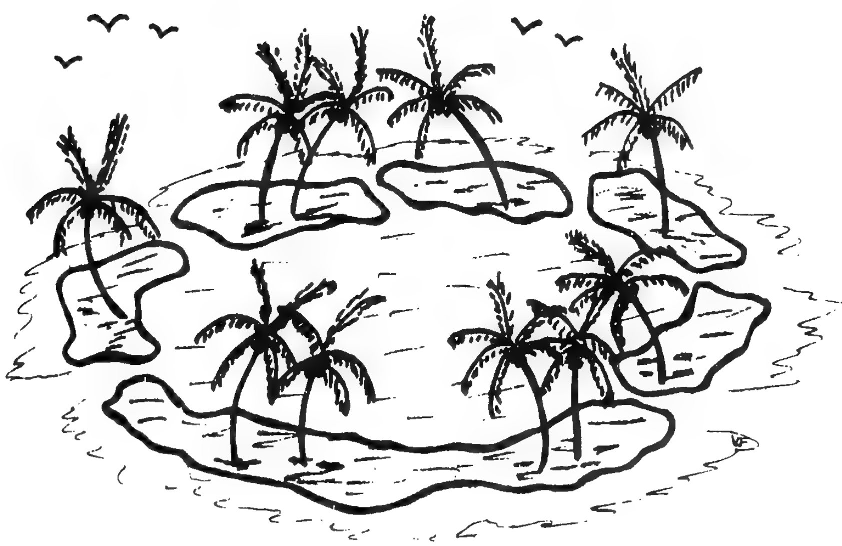

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Washington, D. C., U.S.A.

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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past fifteen years.

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ATOLL RESEARCH BULLETIN

No. 88

Coral Islands

by

Charles Darwin

with Introduction, map and remarks

by D. R. Stoddart

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Introduction

Charles Darwin, writing in his Autobiography towards the end of his life, looked back to some of his earliest scientific work associated with the voyage of the *Beagle*, and was able to "reflect with high satisfaction" on "solving the problem of coral-islands."[1] During the *Beagle* expedition Darwin had crossed the Pacific Ocean, calling at Tahiti, and then the Indian Ocean, making his famous observations at Cocos-Keeling Island, and on his return home he had given a number of papers to the Geological Society of London. Among them was one announcing his theory of coral reefs, "On certain areas of elevation and subsidence in the Pacific and Indian Oceans, as deduced from the study of coral formations," in which he outlined the scheme whereby fringing reefs were converted into barrier reefs and then into atolls by slow subsidence of the island-foundation. This was the first public announcement of the theory, and it met with a favourable response, especially from Lyell.[2] The substance of this paper was embodied, and greatly extended, in the *Journal and Researches 1832-1836*, published in 1839 to accompany the official account of the voyage by FitzRoy, and Darwin's ideas were given definitive treatment in the first edition of *The structure and distribution of Coral Reefs*, published in London in 1842.[3]

In his Autobiography, Darwin has this to say about the formulation of his theory:

> "No other work of mine was begun in so deductive a spirit as this; for the whole theory was thought out on the west coast of S. America before I had seen a true coral reef. I had therefore only to verify and extend my views by a careful examination of living reefs. But it should be observed that I had during the two previous years been incessantly attending to the effects on the shores of S. America of the intermittent elevation of the land, together with the denudation and the deposition of sediment. This necessarily led me to reflect much on the effects of subsidence, and it was easy to replace in imagination the continued deposition of sediment by the upward growth of coral. To do this was to form my theory of the formation of barrier-reefs and atolls."[4]

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[1] All notes pertaining to the Introduction are to be found on p. 4.

The Beagle had been working on the west coast of South America in the earlier part of 1835, and it would therefore be of interest to know when and in what form Darwin first expressed his ideas. In the original Diary of the voyage, he describes the effect of the sight of the reef-encircled Eimeo (Moorea), as seen from Tahiti on 17th November 1835, and on 12th April 1836, in his description of Cocos-Keeling, he plunges into his theory without further ado (this passage was much extended when the Diary was rewritten for publication as Journal and Researches):

> "If the opinion that the rock-making Polypi continue to build upwards as the foundation of the Isd from volcanic agency, after intervals, gradually subsides, is granted to be true; then probably the Coral limestone must be of great thickness. We see certain Isds in the Pacifick, such as Tahiti & Eimeo, mentioned in this journal, which are encircled by a Coral reef separated from the shore by channels & basins of still water. Various causes tend to check the growth of the most efficient kinds of corals in these situations. Hence if we imagine such an Island, after long successive intervals to subside a few feet, in a manner similar, but with a movement opposite to the continent of S. America; the coral would be continued upwards, rising from the foundation of the encircling reef. In time the central land would sink beneath the level of the sea & disappear, but the coral would have completed its circular wall. Should we not then have a lagoon Island? - Under this view, we must look at a Lagoon Island as a monument raised by myriads of tiny architects, to mark the spot where a former land lies buried in the depths of the ocean ..."[5]

The theory was therefore by this time fairly well thought out, and in a letter to his sister, Caroline Darwin, sent from Port Louis, Mauritius, on 29th April 1836, Darwin explained that "The subject of coral formation has for the last half year been a point of particular interest to me. I hope to be able to put some of the facts in a more simple and corrected point of view, than that in which they have hitherto been considered."[6]

Hence, from about November 1835, Darwin had been seriously exercised on the coral reef problem. It was on the 9th November that he first caught sight of "Lagoon Islands" as he called them, in the Low or Dangerous (Tuamotu) Archipelago, and on the 15th he arrived in Tahiti. There he stayed until 3rd December, when the Beagle sailed for New Zealand, arriving on the 21st, and then for Australia. He left Australia on 14th March for Cocos-Keeling, where he spent eleven days in early April, and made his way home by South Africa and South America.

Among the Darwin papers preserved in the University Library at Cambridge, there are two items entitled Coral Islands, one in Darwin's own hand, the other a fair copy with corrections in Darwin's hand. The first is clearly dated 1835, and it includes in the course of the exposition, an account of Darwin's view of Moorea from Tahiti recounted in the Diary for 17th November 1835.[7] There is no mention of the Cocos-Keeling Island. It thus seems very probable that Darwin wrote this outline on the voyage between Tahiti and New Zealand (3rd-21st December 1835), and it

is therefore at least three months earlier, and much longer, than the Diary entry for 12th April 1836, given above.

The original is written on sheets of unlined paper 15.6 x 10.15 inches, folded once to give pages of 7.8 x 10.15 inches. There are twelve such 'sheets' of four pages, and generally the text is written on pages 1 and 3, with the notes to each page of text either on the verso, or in the case of page 3, occasionally opposite on p. 2. In the twelfth sheet, page 4 is also devoted to text. Each page of text, apart from the first, is headed "1835. Coral Islands" and the text-page number. The note-pages are not numbered, and can be referred to as [1a], [2a] ... The detailed composition is as follows:

Sheet 1	Page	1	Text	[1a]	Notes	2	Text	[2a]	Notes
2		3	Text	[3a]	Notes	4	Text	[4a]	-
3		5	Text	[5a]	-	6	Text	[6a]	-
4		7	Text	[7a]	-	8	Text	[8a]	-
5		9	Text	[9a]	Notes	10	Text	[10a]	-
6		11	Text	[11a]	Notes	12	Text	[12a]	Notes
7		13	Text	[13a]	Notes	14	Text	[14a]	-
8		X15	Text	[X15a]	Notes	X15[b]	Text	[X15c]	Text, notes
9		15	Text	[15a]	Diagrams	16	Text	[16a]	Notes
10		17	Text	[17a]	Notes	18	Text	[18a]	-
11		19	Text	[19a]	Notes	20	Text	[20a]	Notes
12		21	Text	[21a]	Notes	22	Text	[22a]	Text

The text has clearly been written in haste: there are many erasures, later cancellations in ink and pencil, and some repetition of notes in the text. This seems to indicate that Coral Islands is Darwin's own first full draft of his theory,[8] and it is quite possible that it was stimulated by his sight of Moorea and its encircling reef,[9] even though the theory had been slowly formulating since the middle of the year.

The Fair Copy is written on feint-ruled foolscap, in units of four pages, each 7.8 x 12.5 inches. As with the original the text is written on pages 1 and 3 of each unit. There are a number of pencilled comments of a critical nature, some erased, in a hand other than Darwin's (possibly FitzRoy's), with brief answers to them in Darwin's hand.

The text presented here* is a transcript of the original paper in Darwin's hand, retaining his spelling and punctuation. In the absence of any earlier manuscript on his coral reef theory, it is thought to be the first full statement he ever wrote. The original and Fair Copy are contained in Volume 41 of the Darwin manuscripts at Cambridge.**

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* Two text-pages of the Darwin manuscript, with their running-heads and marginal notes, and with the notes referring to them, are included in one Bulletin page. The numbers in [] refer to the note-pages, as above. Remarks, or other editorial details, furnished by Mr. Stoddart are also in []. Eds.

** The three sample pages reproduced here, actual size, are from the original manuscript (photos furnished by the University Library, Cambridge).

Acknowledgments

I am indebted to Sir Charles Darwin for permission to publish this paper, to the Library of the University of Cambridge for access to the manuscripts, and to Mr. P. J. Gautrey for his assistance. Dr. Sydney Smith kindly gave me further information on the manuscript and other collections; and Lady Nora Barlow has read the manuscript and given me much encouragement.

Notes

1. The Autobiography of Charles Darwin 1809-1882. With original omissions restored. Edited by Lady N. Barlow. London, 1958, 253 p. (written in 1876). See p. 80.

2. Charles Darwin: On certain areas of elevation and subsidence in the Pacific and Indian Oceans, as deduced from the study of coral formations. Proc. Geol. Soc. London, 2, 1837, 552-554. On Lyell's response to the theory, Autobiography, 1958, pp. 83-84, and 100, and letter from Lyell to Sir J. Herschel, May 24th, 1837, in: K. M. Lyell (editor): Life, letters and journals of Sir Charles Lyell, Bart. London, 2 vols,1881, see Vol. 2, p. 12-13. Compare C. Lyell, Principles of Geology, 1st edition, Chapter XVIII, Corals and coral reefs, 1832 (Vol. 2, p. 283-301) (and similar accounts in editions 2, 3, 4, and 5) with Chapter XVIII, Formation of coral reefs, in Principles, 6th edition, Vol. 3, 1840, p. 366-406.

3. Charles Darwin: Journal and Researches 1832-1836. (Narrative of the surveying voyages of His Majesty's Ships Adventure and Beagle, between the years 1826 and 1836 ..., Vol. 3). London, 1839, 615 p. Charles Darwin: The structure and distribution of coral reefs. London, 1842, 214 p.

4. Autobiography, 1958, p. 98-99. See also Professor C. M. Yonge's essay "Darwin and coral reefs," in: S. A. Barnett, editor, A Century of Darwin. London, 1958, p. 245-266.

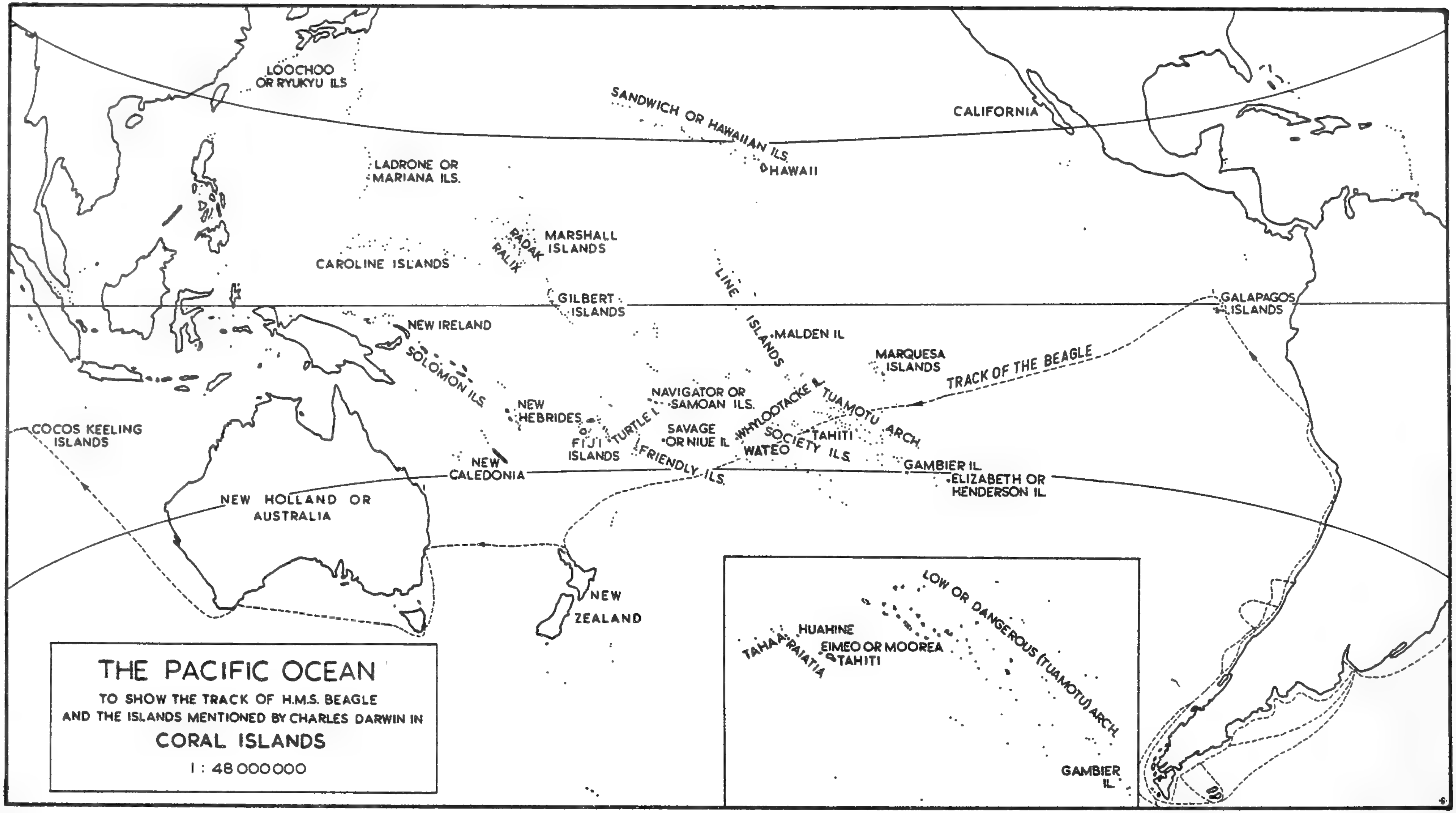
5. Charles Darwin's Diary of the voyage of HMS Beagle. Edited from the MS by Lady N. Barlow. Cambridge, 1933, 541 p. See p. 400.

6. In Lady N. Barlow, editor: Charles Darwin and the voyage of the Beagle. London, 1945, 279 p. See p. 137.

7. Coral Islands, manuscript, p. 4-5; compare Diary, 1933 p. 348, and Journal, 1839, p. 484-485.

8. Lady Barlow has described jottings outlining the theory in one of Darwin's field note-books, probably written in July 1835; see Charles Darwin and the voyage of the Beagle, 1945, p. 243-244.

9. "I was much struck with this fact [the lack of "essential difference between encircling barrier-reefs and atolls"] when viewing, from the heights of Tahiti, the distant island of Eimeo ..." (Structure and distribution of coral reefs, 1842, p. 46). Also reference in note 7, above.


THE PACIFIC OCEAN
TO SHOW THE TRACK OF H.M.S. BEAGLE
AND THE ISLANDS MENTIONED BY CHARLES DARWIN IN
CORAL ISLANDS
1 : 48 000 000
LOOCHOO OR RYUKYU ILS
SANDWICH OR HAWAIIAN ILS.
HAWAII
CALIFORNIA
LADRONE OR MARIANA ILS.
MARSHALL ISLANDS
RADAK
RALIX
CAROLINE ISLANDS
LINE ISLANDS
GILBERT ISLANDS
GALAPAGOS ISLANDS
NEW IRELAND
MALDEN IL
MARQUESA ISLANDS
SOLOMON ILS
TRACK OF THE BEAGLE
NAVIGATOR OR SAMOAN ILS.
WHYLOOTACKE IL
TUAMOTU ARCH.
NEW HEBRIDES
TURTLE I.
SAVAGE OR NIUE IL
SOCIETY ILS.
TAHITI
WATEO
COCOS KEELING ISLANDS
FIJI ISLANDS
NEW CALEDONIA
FRIENDLY ILS.
GAMBIER IL.
ELIZABETH OR HENDERSON IL.
NEW HOLLAND OR AUSTRALIA
NEW ZEALAND
LOW OR DANGEROUS (TUAMOTU) ARCH.
HUAHINE
EIMEO OR MOOREA
TAHAA
RAIATIA
TAHITI
GAMBIER IL.

Although I have personally scarcely seen anything of the Coral Islands in the Pacifick Ocean. I am tempted to make a few observations respecting them.-

In looking at a chart of the East Indian group. it will be seen that a direction within a couple of Points of NW & SE is common to the Western & Eastern Islands.-This line is continued to New Caledonia.-It is fronted
a) by the parallel chains of New Ireland. Solomon & Hebrides Isl[ds].- [Perhaps the similar direction of the North part of New Zealand & that part of New Holland, which in its position & barrier of Corall reefs is intimately connected with the South sea, may be more than an accidental coincidence.- [1]] Those small Islands, which stretch in an E.W direction half way across the Pacifick, are frequently described as being a curved part of that Volcanic band of Islands which terminates Southward at the New Hebrides, or more properly in New Zealand.-

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[1. This sentence is deleted in the original, and the following note is given on page 1a:]
(a) Again we see the same fact in the northern part of New Zealand; the constitution of which, like the foregoing Islands, is essentially Volcanic.- The NE coast of Australia which is fronted by the great barrier reef & so intimately connected with the Pacifick, has also a NW & SE direction. The whole shore is believed to consist of Granitic rocks; a little way inland a long chain of hills runs parallel to the coast line.- (Dr Fitton's Appendix to King's Australia)

* * * * * * *

But I do not think this is a correct view.-In each separate Archipelago the direction already alluded to is found.- This law prevails even
(a) as far as the Sandwich Is[ds] (a).- Perhaps the strongest exception will be
(b) discovered in the Friendly Is[d] that is if these are taken without reference to the group of the Fidjis. All the Islands ought rather to be considered as so many short parallel lines, than the continuation of the great volcanic band which sweeps round the Eastern shores of Asia.- I have pointed out this fact, as showing a degree of physical connection in the Islands of Polynesia. Forster in his observations in a Voyage round the World. makes three classes for the different kinds:- (1st) High Islands without Coral reefs; he adduces as Examples the Marquesas & Hebrides. & two out of the Friendly Is; to them may be added the Navigators

---

[2a] (a) I may even add the peninsula of California & the shores of North America.-
(b) Mem. the Friendly a field of modern disturbance. & therefore the exception of Value.-

as described by Kotzebue. the Sandwich & Galapagos groups & several other smaller ones.- It would be a curious point to ascertain, whether Coral grows abundantly on the shores of any of these Islands, although not forming a reef; or whether as at the Galapagos, it may be considered as absent.- This one fact would alone throw much light on the theoretical structure of all the Coral formations.- We know that in some parts of the World where Corall is abundant, as in the West Indies true Lagoon Islands do not occur. II. High Islands encircled by a reef, as a picture is by a frame.- the singularity of this phenomenon, the beauty & utility of its
(a) effect has scarcely been enough insisted upon by Voyagers.(a)- Forster gives an example in Tahiti, & all the true Society Islands, the higher ones of the Friendly & New Caledonia.- III The low half drowned Islands, composed entirely of Coral

---

[3a] (a) It must be borne in mind, that the line of breakers sweeps round, at a considerable distance from the foot of the mountains.- The interval is occupied by the smooth water of the lagoon & the low alluvial land. which has encroached on parts of its former bed.-

* * * * * * *

& including a lagoon.- IV. Capt Beechey has described another class, such as Elizabeth. Savage * Wateo Island, (a) which are composed of Coral rock, are of moderate height, & probably before their elevation existed as Low or Lagoon Islands.- Capt. Beechey remarks on the rarity of this class.- I suspect however on a more accurate knowledge. several more will be added to this list. I may perhaps instance Turtle Isd. of Cook. which Forster brings forward as the best example of subterranean elevation in the Pacifick.- With respect to this classification, it appears to me that the distinction between the II & III division, or the high islands with reefs & the Lagoon ones, is artificial.- I believe the reefs and strips of land, which compose the circular Low Islands. are of the very same structure & origin with those reefs which encircle, as with a belt so many of the lofty ones.- Viewing the Ei Meo

---

[Marginal note, same page] (a) & Perhaps Malden of Ld. Byron

from the heights of Tahiti I was forcibly struck with this opinion.- The mountains abruptly rise out of a glassy lake, which is separated on all sides, by a narrow defined line of breakers, from the open sea.- Remove the central group of mountains, & there remains a Lagoon Is.d - I ground this opinion from the following facts.- There is a general similarity in the two cases in the form & size of the reefs; their structure appears identical, we have scarcely fathomable water in each case, at a short distance on the outer margin; within is a shallow basin more or less filled up by knolls of growing Corall or converted into dry land.- In the Lagoon Isl.ds there are some, which do not deserve this title, for they consist solely of a circular reef, of which scarcely a point projects above the water;(a) whilst others have a more or less complete, but narrow ring of dry land.- In the same

[Marginal note, same page] (a) Such as the Is.d near Turtle I.

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manner in the encircling reefs, although they generally are only ornamented by a few speck formed Islands, yet at the fine Island of Huahine Ellis states the reef is becoming converted into dry land.- The essential character in the one class, of a large encircled Isld. itself dwindles away & becomes ambiguous.- We have the 2 large Islands of Raiatia & Taha (?) included in one reef.- In such cases, as in Gambier Is.d so well described by Capt Beechey, where a group of small hilly Islands are encircled by one grand reef, or as in Whylootacke. (seen by the Beagle) when one single one is so situated, it becomes a question in which of the two classes they ought to be arranged.- In the Is.d of Caledonia, as drawn on a large scale in Krusenstern's Atlas, the reef will be seen prolonged at each extremity. & encircling the continuation,

beneath the water of the land. It here requires less effort of imagination to remove the central hills & to leave a perfect lagoon Is^{d} - this change judging from the figure, it might be believed was actually in process.- The last argument which I can adduce is the parallelism between the Archipelagoes of the two orders, for instance the low Island & the Society ones.- Moreover, this parallelism is found in the direction of the longer axis of the oval figure, which is so frequent in the encircling reefs & low Island:- One is tempted to extend still further this similarity & to believe that there is no difference between the reef which encircles an Island, & those extraordinary barriers of Coral, which front for so many leagues the coast of Australia & I believe the Northern shore of Brazil.- The high encircled Isds. are composed of various geological formations: no

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doubt ancient Volcanic rocks are most abundant, but in Tahiti M. Hoffman found Granite. Mr. Ellis states. that in several of the Society Is^{ds} Granite, Hornblendic rock, Limestone & rock with Garnets is found. Forster in New Caledonia describes the prevalent rock under the name of Gestele stein, which I believe to be Mica Slate.- Hence we may feel secure (if any doubts could have been entertained) that these encircling reefs are not built on the crests of submarine Craters.- If the proofs of the identity in nature of the two kinds of reefs, are considered as conclusive, in a like manner, there is no <u>necessity</u> that the Lagoon Isd. should be based on such Craters. This view will I think, generally be more satisfactory, it removes the difficulty of the immense size of the Lagoons far exceeding any known Crater: & explains the extreme irregularity of figure. exemplified in the Radack

& Ralix groups, described by Kotzebue. Whether we look at these Islands.
as having formerly encircled high land, or resting on the brim of a Crater,
[1] it appears to me, we must admit, the theory of Mr Lyell, that their
present structure is owing to a series of small depressions.- If the
ground on which the Lithophytes have built their edifices has not
subsided. it must have remained stationary or been elevated. [It being
allowed that the Corall animal can flourish only at a small depth. it
(a) follows, on the first supposition, that all the submarine mountains
within this limit had the same height & that not one raised its head
(a) above the level of the sea.[2]] On the second supposition. of a series
of elevations; these movements over a large tract of ocean, ceased. &
never exceeded the limits already pointed out.- Now, these consequences
from the two suppositions, are so very improbable: (for if they are not so,we

[1. Marginal note:] Vol II Chapt: XVIII
[2. This sentence is deleted in the original, and the following note is given on page 9a:]
(a) On the first of these suppositions. it being allowed. that the Coral animal can only flourish at a small depth, it follows that submarine mountains, on which the Coral is now growing. reached within the limits of such depth, the surface, but yet that not one peak ever raised its head above this level.-

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might expect to find somewhere a tract of country with mountains of an equal height) that to my mind the evidence of subsidence the only remaining supposition is demonstrative.- No doubt the fourth class of Islands, the raised Coral rock, is an argument on the other side; but their acknowledged rarity appears to me a proof that they ought rather to be considered as exceptions or irregularities in the prevailing movement. If a gradual upheaval was in progress here, as on the shores of S. America. the Coral would afford a more palpable and lasting evidence, than could be expected under any other circumstances.- Capt. FitzRoy has discovered an interesting tradition amongst the Low Islanders, that the arrival of the first Ship. was followed not long afterwards by a great inundation which destroyed many people.- Earthquakes are occasionally experienced here; at Tahiti there happened one which was believed to have foretold the arrival of the first Missionaries.

I looked in vain on the shores of Tahiti for any sort of evidence of a consequent rise.- In the Polynesian traditions (Ellises Researches) there are accounts of deluges, which evidently were accompanied by Volcanic phenomena.- The difficulty in understanding the cause of a reef of living Coral, being separated by channels or lakes from the land. has not as yet. been attempted to be removed. The only explanation. which I can offer. is
(a) chiefly conjectural.[a] - when at Tahiti I examined the reef.- I found on
(B) the exterior margin, a solid broard [sic] (30-50 yards?) mound of Coral
(A) rock, strikingly resembling an artificial (but low) breakwater. on which the surf beat with violence.- The surface of the mound is compact &
(C) smooth.- It is slightly curved & dips towards the inside or smooth water of the Harbor. Owing to the surf. I could not examine the outer margin; I am told it consists of

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[11a] (a) It rests on a belief that the species of Coral, most efficient in building a reef, flourish best when immersed in the surf of the outer breakers, & that their growth is checked by sediment & fresh water brought down from the central land.-

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smooth ledges of <u>living Coral</u>, & that its general inclination is great:- It is only on rare occasions, when there happens to be very little surf & a low tide that the living parts can be seen. Not unfrequently after gales of wind, the ledges (probably overhanging) are torn up & in enormous masses thrown far up on the reef: By this means also the Natives know the exterior margin is thus constituted. The central part of the breakwater is entirely dead; on its surface the chief production is an encrusting inarticulate <u>Corallina</u>. The sea, breaking violently on the outer margin, continuouslypumps over in sheets the water of its waves.- hence the surface is worn smooth & gently declines towards the lagoon.- I was assured that on the rare occasions, alluded to, the central part is exposed, uncovered to the rays of the sun, & that this invariably kills
(a) the animal, & leaves the Lithophyte dead rock.

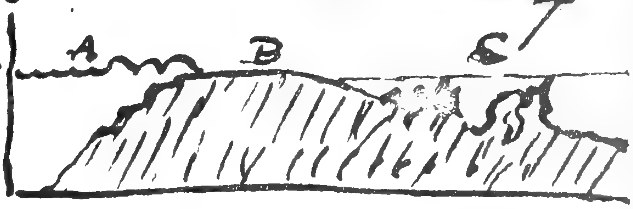
(a)

[12a] (a) There must however be some process by which the mound is repaired: if once worn away so deeply as always to be covered by the water, the case becomes at once similar to the outer parts; perhaps the Corallinas & other small Marine productions may protect the surface.-

I looked in vain on the shores of Tahiti for any sort of evidence of a consequent rise. — In the Polynesian ~~[illegible]~~ traditions (Ellis's Researches) there are accounts of deluges, which evidently were accompanied by Volcanic phenomena. —

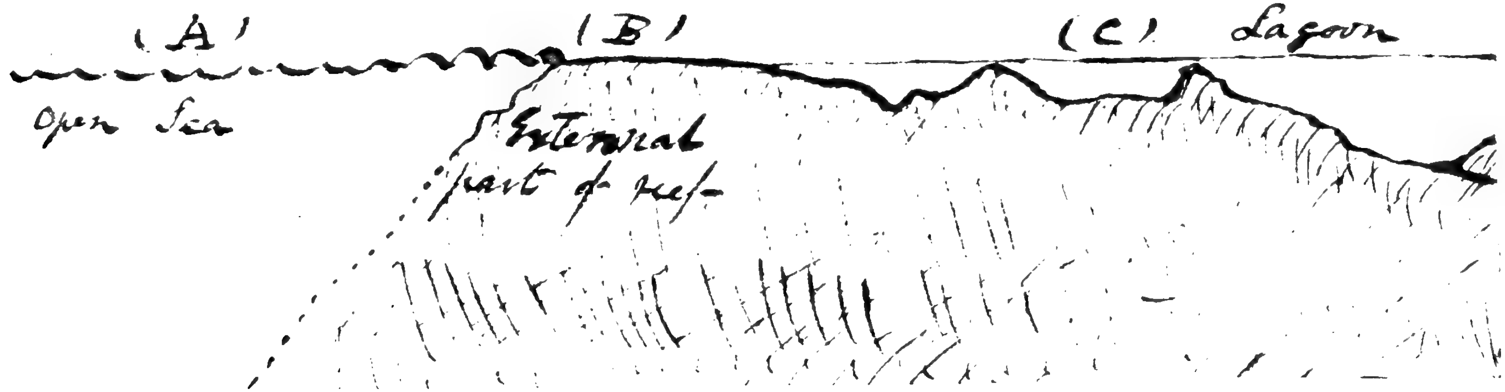
The difficulty in understanding the cause of a reef of living Coral, being separated by channels or lakes from the land, has not as yet, been attempted to be removed. The only explanation, which I can offer, is chiefly conjectural. — When at Tahiti I examined the reef. — I found on the exterior margin, a solid broad, (30–50 yards?) mound of

(B) Coral rock, strikingly resembling an artificial (but low) breakwater, on which the ~~Surf~~ beat with violence. —



(A) The surface of the mound is compact & smooth. — It is slightly curved & dips towards the

(C) inside or smooth water of the Harbor. ~~From~~ Owing to the surf, I could not examine the outer margin; I am told it consists of



This revised version of the sketch on Darwin's page 11
occurs on a separate piece of paper inserted in the Fair Copy.

The whole reef may be described, as consisting of two parts: the outer margin of the Breakwater, the solid part of which is higher than all the rest, & a tract of very shallow water which varys in width from 100 yards to a mile. In this low part there are little narrow twisting channels & holes of deep water, & on the other hand many points. where the Coral reaches to the surface. It is in this still water where an observer as has often been described, may watch the fish gliding amongst groves of variously coloured Corals. This part of the reef seldom or never is directly joined to the shores: but there is left channels & harbors where a Ship can anchor in a fine Sandy bottom.- I imagine it is the fresh water & sediment brought down. which helps to prevent these spaces being filled up & likewise perhaps the cause that these reefs are seldomer
(a) converted into stripes of dry land. than in the Lagoon Is^ds.- In the shallow parts the most abundant kind of Lithophytes, are stony & branching. generas (as). Also Fungia & Caryophillia

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[13a] (a) When such does happen. that part close within the breakwater would from the fragments thrown over it, be soonest changed.- there also the water is pure & fit for the growth of some kinds of Coralls.-

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Showing them to some intelligent natives I was assured that such kinds never grow on the outside of the reef or compose solid reefs.- From their descriptions. I imagined the prevalent kinds, so situated are such as Porites. Millepora. & some Meandrina & Astrea. Anyhow they appeared to consider that there is a wide distinction in the two cases. Analogy. from the habits of all other marine animals would lead one to suppose that the <u>same</u> species would not flourish in two such different localities, as the foam of furious breakers. & shallow placid lakes. If this opinion should be granted. it would be very important; we might infer that those species. which build the external solid wall, the <u>highest</u> & most perfect part of the Corall rock, will only flourish where the waters break
[1] violently. M. Quoy & Gaimard, state, "that the species, which constantly formed the most extensive banks, belong to the genera. Meandrina, Caryophyllia. & Astrea" & that the Saxigenous polypi increase most considerably in shallow & quiet water. I am not aware whether they suppose, these same species form the outer parts of the reefs.

[1. marginal note:] D. L. Beche

With respect to the ratio of increase I have a few remarks to offer.- In the greater number of the Lagoon Is^{ds} from the arguments already used, it is clear no movement of elevation has taken place.- Now Capt. Beechey remarks, that the strips of dry Coral, divested of any loose sandy materials heaped upon them are rarely elevated more than 2 ft above the level of the sea. Now whatever this elevation may be, it is clear, that the highest point of the living Coral rock is in any Is^{d} as high or higher than the dead. Because the dead. lived under similar circumstances & may have suffered degradation.- Now this quantity is so much higher than the level of the ocean & therefore than the waters of the Lagoon, which must afford the nearest approximation to judge by.- Hence the Coral, which has formed the strips of dry land, could not have been cherished by those quiet waters, but rather in the turbulence of the breakers, where a surface above the mean

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level. would never remain uncovered & exposed to the rays of the sun.(x)- In those cases where true Coral rock is above the level of the Lagoon.
(a) the land must have increased outwards;(a) but as it appears from the extreme depth. beyond the reef, that this can hardly be a general process. I suspect that Coral rock may often be difficult to be distinguished from a rock of cemented fragments.- Besides the greater absolute height of the Coral which grows in the surf, it must be remembered, that yearly gales of wind, tear off large fragments, some of which are tossed on the reef & others must fall down into the surrounding depths. Yearly the Polypus has to replace this damage.- On the other hand, within the lagoon all detritus accumulates, & if as according to M. Quoy and Gaimard. the Coral grows there also most rapidly; how comes it that the Lagoon is not more commonly filled up? This is the more surprising. if we look at the entire section of a Lagoon Island in Capt. Beechey. & see how trifling the inequality of the foundation

XXX

[X15a:] (x) This conclusion perfectly agrees with what was visible in the reef of Tahiti.

[X15c:](a) as appears to have been the case. on the Is^{d} on which Capt. Beechey found the remains of the wreck of the Matilda so very singularly situated.

[Note on verso of Leaf 11 in Fair Copy:] Insert this as a note stating my previous formed opinion.

Note - May not earthquake waves be occasional agents?- May not the wreck of the Matilda have been thrown inshore by a great wave?- Such an event happening once in a century- as at Lima or Concepcion - would hardly be known to the few Europeans who have yet examined Polynesia.

really is. And we must also bear in mind that arguments can be advanced to show that the subsidences must happen after long intervals.- such as few proportionate numbers of submerged circular reefs; & again the quantity of detritus heaped up on the dry Coral.- The general tenor of the foregoing facts, strongly urges me to believe that the Coral, most effective in forming the solid reef, will only flourish near to the break of the Sea.- I will not pretend to conjecture concerning the cause of this prediliction, whether the motion of the fluid, or the quantity of insolved[1] air. is favourable; or whether the light and heat, which must pervade still shoal water is injurious to the growth of their Species.-

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[1. In the Fair Copy, insolved is rendered intangled.]

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1835 Coral Is^ds^ 15

[respect to the ratio of increase, it must be remembered, that all the Coral. which grows within the lagoon. accumulates. whereas on the outside yearly large fragments are torn off & carried away. The Polypi have to repair all this damage. On the supposition that the dimensions of the reef or island do not decrease. (which at least will be granted), the polypi must yearly repair this damage.[1]] - If then the two following postulates are allowed, much of the difficulty in understanding the Coral formation. will I think, be removed.- (1st) That in certain parts of the Pacifick, a series of subsidences have taken place; of which no one exceeded in depth, the number of ft, at which saxigenous polypi will flourish: & of which series, the intervals between the successive steps. were sufficiently long to allow of their growth, always bringing to the same level the upper surface of the reef.- (2nd) That those species of Lithophytes, which build the outer. solid wall, flourish

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[1. These two sentences deleted in the original, and their substance expanded in the two pages marked X15 and in [X15c], clearly added after this section of the text was written.]

(a) best, where the sea violently breaks.-
Better to explain my views, I will take the case of an Island situated in a part of the ocean. which we will suppose at last becomes favourable to the growth of Corall.- The circumstances which determine the presence or absence of the Saxigenous Polypi are sufficiently obscure, but they do not enter into this discussion.- Let AB represent the slope of an Island so circumstanced & CD the level of the ocean. Then Corall would immediately commence to grow on the shore (D) & would extend Sea-ward as far as the depth of water. would permit its rising from the bottom.- Let this point be (H).- The breadth of the reef (HD) would then depend, on the angle of inclination of the bottom.- This space might either be converted into a piece of Alluvial ground, or even, from the Corall springing up vertically from E & so protecting the inner space, might exist as a Lagoon.-

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[16a] (a) This second Post: is not so necessary as the first: as will be subsequently seen.- Possibly the fact of the Windward side of the low Islands, where the surf generally is most violent, being the highest & most perfect. may be partly explained by such an admission.-

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This reef would however essentially differ from those in the South Sea, in the depth of the water. (I exclude any few exceptions) beyond the Wall not suddenly becoming excessive.- If the level of this Island should remain stationary. I cannot imagine any change.- But if the land should be raised. (or sea sink): the outline would be as represented by the dotted line.- And on the shores. a fringe of Dry Coral rock would be left: This circumstance is known to happen in the East & West Indian Is[ds]- Some such fact, may perhaps explain the double reefs found by Capt. Beechey at Loo Choo, one of which was dead & one living.- Now if we suppose the land gradually to subside (See Fig. II. I have represented the water rising; the effect of course is the same) the level of the sea will stand at Cl instead of at CD.- The Coral of the outer wall favoured by the heavy surf.
(a) will soon recover its former level.[a]- If this process.

[17a] (a) or the whole may be supposed to have same tendency to grow up & recovers its former level: but that the sediment &c from the land checks its growth.

(a). best, where the sea violently breaks. —
Better to explain my views, I will take
the case of an Island situated in a part
of the ocean which we will suppose at
last becomes favourable to the growth of
Corals. — The circumstances which determine
the presence or absence of the Saxigenous
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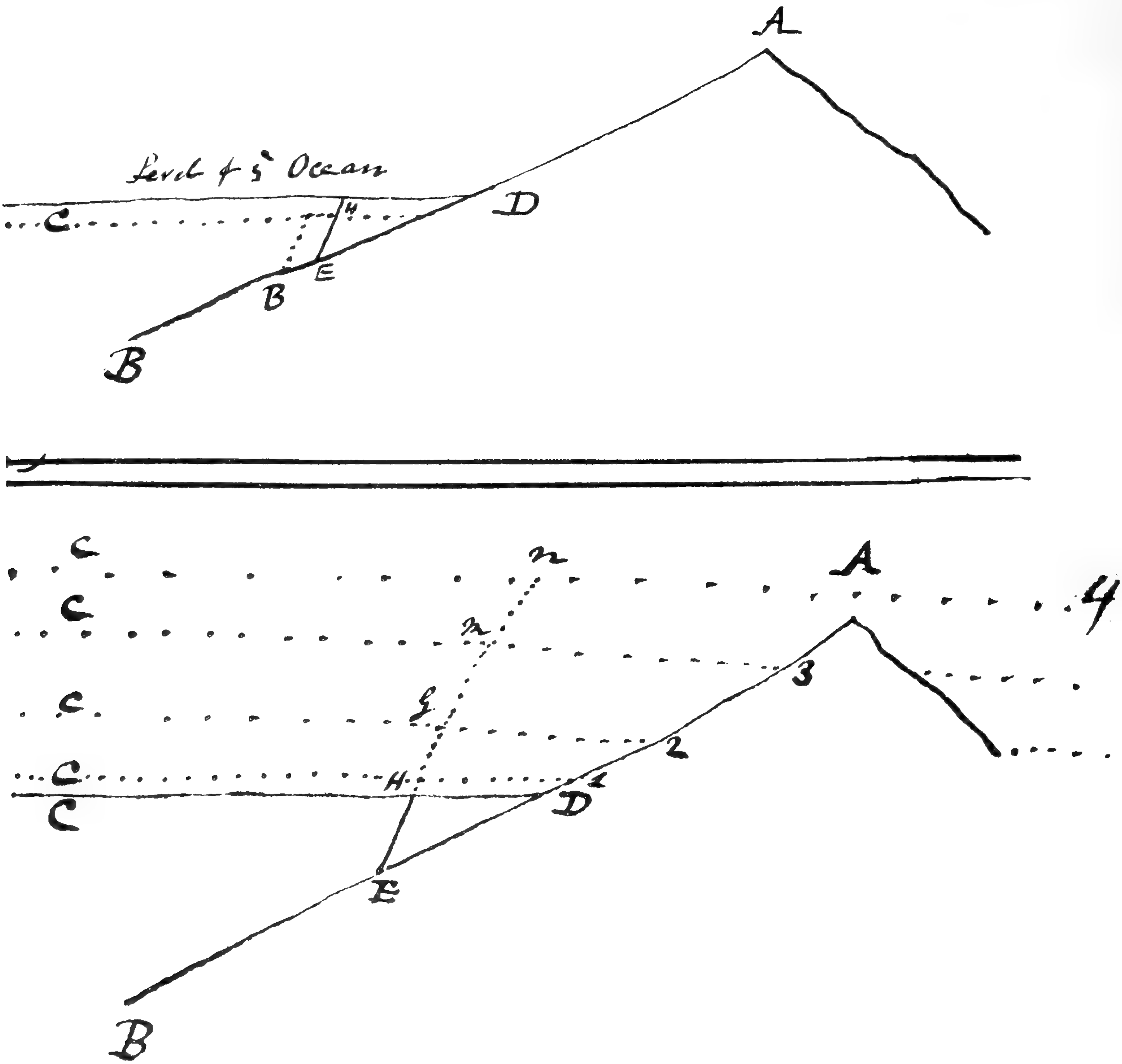

Fig II

is repeated each time the sea will gain on the land while. the reef rises, nearly vertically on its first foundation.- I say nearly vertically, because, any & every small portion removed in front of the lower part & the building being continued upwards before its repair, this must throw backwards the whole of the superstructure. When the level stands at (C3), the space between the reefs & the land, will be more, than twice as broard as at first. This space will probably be occupied by a lake of water. such still water. not being favourable to the growth of the most efficient species of Coral.- I may mention that when at first the reef touched the shore. in the mouth of each stream. there must have been a channel.- such openings. during the longest series of depressions. would be continued & hence would generally

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(a) face the valleys, as is observed to be the case.[a]- This explanation is referrible to those reefs which front a continent or encircle an Island.- If the subsidences are continued, till by the encroachment of the water an Island is reduced from large to small, & is at last totally submerged; then there will remain a true Lagoon Is[d]- When viewing Ei meo, or the chart of New Caledonia. I talked of removing the central mass of hills, this was the process I was considering. If the above hypothesis, all its
(b) parts considered together, is considered even as partially satisfactory (for I am aware several objections can be raised against it) it will be worth while to follow out some of the more extended consequences. In those parts of the world, where a general movement upwards is in progress, we ought not to find groups of Lagoon Is[d] or that class of reefs. which encircles the land at a distance & has very deep water close to the outer wall. How far this is actually the case I have not

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[19a] (a) These channels would generally have about the same depth as the lagoons; their bottoms being filled up with sand or detritus.- The action of currents would prevent their total filling up.-
(b) I must observe that in the early part of the series of subsidences, there can be little doubt that the fresh-water & sediment, brought down from the central land, would be injurious to the growth of the Coral within the reef.- But when a Lagoon Island was once formed, (excepting the prejudice caused by the accumulated sediment, as a slippery foundation) we must look to the other reasons as an explanation of the continuation of the inequality in growth.-

sufficient data to judge. In the West Indies, where proofs of recent elevation are abundant, reefs of these structures are not found. or at least are not common.- Within the East Indian Islands, the shores of which are frequently overlaid with raised Coral rock, I believe likewise they
(a) are not found.- In the Pacifick I may adduce the Sandwich Is^d.- It will be interesting to discover. whether those groups (our first class) which are not protected by reefs, but yet have Corall abundant on their shores can
(B) be proved to have been recently elevated.^B- If such generally is the case, it will give much probability to the idea, that the direction of the movement determines the structure of the reef.- It is manifest that a Lagoon Isd. might be raised s trifle, by an oscillation in the general movement without its character being lost.- This appears to have happened
[1] at Turtle Is^d. (Cook), which Forster brings forward as the best instance of subterranean upheaval in the Pacifick.- Plants are described on the reef as growing on the dead Coral, which is raised above the

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[1. marginal note:] (P. 147)
[20a] (a) How are the Ladrones (which have dead Coral on the surface)? V. Kotzebue II Vol.-
V. some large Chart. Kotzebue gives no information on the subject.- Note
(B) Mr. Bennet informs me that in the New Hebrides, which are thus circumstanced he found dead coral at an elevation of 1500 ft.- Vide Wanderings in New S. Wales

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reach of high water.- yet this Island appears to have retained its proper figure. If however such movements were continued, no doubt an Isd of our fourth class would be produced.- Now it is remarkable, that out of the few instances of this Class given by Capt. Beechey, two of these Islands are surrounded by reefs of growing Coral, but these are attached to the shore, not being separated by channels or lakes of water. I allude to
(a) Henderson I described by Capt Beechey himself & Wateo by Cook.-

On the opposite supposition of a general progressive subsidence in any part of the World (of course I include only those favourable to the growth
(b) of Coral) we should expect to find either or both Lagoon Is^ds & the encircling reefs.- The archipelago of the Society I^s. (which are encircled) & that of the Low Is^d. occur in the same part of the ocean.- The Friendly Is^d in a like manner are divided into the same two sorts of groups.- As decisive evidence of depressions of

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[21a] (a) V. Byron for structure of Malden Is^d.-
(b) V. Chart of the Barrier of Eastern Australia, are there in that district any lagoon Is^ds?-
Note

level. will almost always be deficient: all that we can look to is that there is no evidence of an opposite tendency. Now against this. a flagrant
[1] instance. can be brought up. from Mr. Ellis' account of the true Society Is[d].- He states, that on the mountains of Raiatia, Coral & shells &c are found. I do not clearly understand that he himself has examined into the circumstances. Perhaps they may be interstratified with the Lavas & only point out a very ancient elevation.- From the mineralogical nature of the strata in Tahiti I felt no doubt, but what they had formerly been submerged beneath the Sea.- To all such general views, as these, many exceptions, may always be expected to be found; to ascertain their truth, a far more extended examination of all the phenomena, is absolutely necessary. If the reality of them should ever be proved, it would be important to Geology. For then we might assume that groups of Lagoon Is[d] clearly showed that a chain of Mountains had there sub-
(a) ___

[1: marginal note] V. Ellis Vol. 1 P. 389

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(a) [22a]
-sided.- And, when in any formation there should be found, a great thickness composed of Coral & the genera of which resembled those, which now build the reefs, we might also conclude. that during its successive accumulation, the general movement, was one of depression.-

Before finally concluding this subject, I may remark that the general horizontal uplifting which I have proved has & is now raising upwards the greater part of S. America & as it would appear likewise of N. America, would of necessity be compensated by an equal subsidence in some other part of the world.- Does not the great extent of the Northern & Southern Pacifick include this corresponding Area?- Humboldt carrys a similar idea still further; In the Fragmens Asiatiques, P 95. he says. "Par consequent l'epoque de l'affaisement de l'Asie occidentale coincide plutot avec celle de l'exhaussement du plateau de l'Iran, du plateau de l'Asie centrale, de l'Himalaya, du Kuen Lun, du Thian shan & de tous les anciens systemes de montages diriges de l'est a l'ouest; peut etre aussi celle de l'exhaussement du Caucau, & du noeud de montagnes de l'Armenie & de Erzeroum."[1]

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[1. The following translation, found on a single sheet in Darwin papers, Vol. 42, folio 23, is transcribed in the final paragraph of the Fair Copy:] Humboldt (Fragmens Asiatiques Page 95) in a similar manner considers that the epoch of the sinking down of Western Asia coincides with the elevation of the platforms, of Iran, of central Asia, of the Himalaya, of Kuen Lun, of Thian Chan, and of all the ancient systems of Mountains, directed from East to West.

Appendix: Works referred to by Charles Darwin

In 'Coral Islands' Darwin makes reference to some fourteen books and papers, listed below. It is probable that not all of these were carried on the Beagle, and the references derive from other sources. For example, Darwin did not read other languages with ease, and his knowledge of the work of Quoy and Gaimard almost certainly derives from De la Beche's 'Geological Manual.' To trace the books relevant to the coral work which Darwin actually had with him during the voyage, we have the evidence of his own writings, in the 'Autobiography, 'Life and Letters,' and 'More Letters' - which together mention only Humboldt, Lyell and a "small volume" of Milton - together with the books remaining in his library at the time of his death, and listed in the following two publications:

H. W. Rutherford. 1908. Catalogue of the library of Charles Darwin now in the Botany School, Cambridge. Cambridge, University Press, 91.

Books received in the University Library from Down House, March-May 1961. Cambridge, University Library, mimeographed (29 p.).

Two books were pre-eminent in his collection: Lyell's 'Principles of Geology' and Humboldt's 'Personal narrative of travels to the equinoctial regions of the New Continent.' The first edition of the 'Principles,' used on the voyage, is now at Cambridge, together with editions 5, 6, 7, 9, 10 and 11, all from Darwin's library. Volume 1 (1830) is inscribed "Given me by / Capt F. R/ C. Darwin;" Volume 2 (1832), containing the chapter on coral reefs, has on the flyleaf "Charles Darwin / M. Video Novem^{r} 1832." The copy of the 'Personal Narrative' is the English translation by H. M. Williams, London 1819-20, 6 volumes in 7, and is inscribed: "J. S. Henslow to his friend C. Darwin on his departure from England upon a voyage round the world. 21 Sep^{r} 1831." Both volumes are annotated. In the coral reef chapter of Lyell, 'Principles,' Volume 2, it is interesting to see that the paragraph in which "subsidence by earthquakes" is advocated to account for the form of atolls has been scored.

In addition to these works, to which Darwin made frequent appreciative references in his letters and 'Autobiography,' he probably also had with him Humboldt's 'Fragmens de géologie et de climatologie asiatiques' (his admiration for the author overcoming his repugnance for French); Captain Beechey's 'Narrative,' a much annotated copy being preserved in the Cambridge collection; and Forster's 'Observations,' also at Cambridge and quoted in 'Coral Islands.' It is clear from 'Coral Islands' that a number of volumes which are no longer in his library were also taken on the Beagle: chiefly Kotzebue's 'Voyage;' Ellis's 'Polynesian Researches;' Bennett's 'Wanderings in New South Wales;' Byron's 'Voyage;' and King's 'Narrative.' De la Beche's 'Researches in theoretical geology,' 1834, is in the library, but not the 'Geological Manual,' 1831, which was probably used during the voyage. We have the evidence of FitzRoy that a copy of Krusenstern's 'Atlas' was carried on the Beagle.

One further relevant volume in the library, which may have been taken on the voyage, is Playfair's 'Illustrations of the Huttonian Theory,' 1802.

From the point of view of 'Coral Islands,' however, it is clear that Lyell, Beechey, Kotzebue, Forster and De la Beche were Darwin's

main sources, together with a collection of voyages and travels now forgotten. The complete list is as follows:

Beche, H. T. de la. 1831. A geological manual. London, Treuttel and Würtz. 535 p.

Beechey, F. W. 1832. Narrative of a voyage to the Pacific and Beering's Strait, to co-operate with the polar expeditions: performed in His Majesty's Ship Blossom, under the command of Captain F. W. Beechey, R. N., F. R. S. &c. in the years 1825, 26, 27, 28. Philadelphia, Carey and Lea. 493 p. (This edition in Darwin's library, annotated).

Bennett, George. 1834. Wanderings in New South Wales, Batavia, Pedir Coast, Singapore, and China; being the journal of a naturalist in those countries, during 1832, 1833, and 1834. London, R. Bentley. Volume 1, 440 p. Volume 2, 428 p.

Byron, George Anson, 7th Baron. 1826. Voyage of H. M. S. Blonde to the Sandwich Islands, in the years 1824-25. Captain the Right Hon. Lord Byron, Commander. London, John Murray. 260 p.

Chamisso, Adelbert von. 1821. Remarks and opinions of the naturalist of the expedition: in, Kotzebue, Voyage, Volume 2, p. 349-433; Volume 3, p. 1-318, and 331-336.

Ellis, William. 1829. Polynesian researches, during a residence of nearly six years on the South Sea Islands; including descriptions of the natural history and scenery of the islands - with remarks on the history, mythology, traditions, government, arts, manner, and customs of the inhabitants. London, Fisher, Son and Jackson. Volume 1, 536 p. Volume 2, 576 p.

Fitton, W. H. 1827. An account of some geological specimens, collected by Captain P. P. King, in his Survey of the Coasts of Australia, and by Robert Brown, Esq., on the Shores of the Gulf of Carpentaria, during the voyage of Captain Flinders: in, King, Australia, Volume 2, p. 566-630.

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ATOLL RESEARCH BULLETIN

No. 89

Geophysical Observations on Christmas Island

by

John Northrop

Issued by

THE PACIFIC SCIENCE BOARD

National Academy of Sciences--National Research Council

Washington, D. C.

December 15, 1962

Geophysical Observations on Christmas Island[1]

by

John Northrop

During October and November of 1961, the Marine Physical Laboratory of the Scripps Institution of Oceanography, in cooperation with the British Atomic Weapons Research Establishment, sponsored a series of geophysical measurements on Christmas Island. Continuous recordings of the earth's magnetic field were made simultaneously at various points on the island under the direction of Ronald G. Mason [2] and John Northrop of the Marine Physical Laboratory of the University of California, San Diego. In addition to these recordings, daily trips by land rover and small boat to various points on the island and in the lagoon were made for the purpose of completing gravity and magnetic measurements with portable equipment. These measurements show a sharp positive gravity anomaly near Motu Tabu, towards the north end of the island, indicating a shallow depth to basement in that area.

1/ This work was partially supported by Contract Nonr 2216 (05) with the Office of Naval Research.

2/ Also of Imperial College, London, England

At 1° 52.7' N/157° 23.9' W, an unusually hot lagoon 1/4 mile long was found to have a bottom temperature of 102° F and a surface temperature of 86° F. The surface layer, about 1/2 inch thick, has a specific gravity of 1.0 and the bottom water 1.4. Since this narrow lagoon is only about 3 feet deep, a marked inverse temperature gradient is present. At the suggestion of Walter Munk of Scripps Institution of Oceanography, the level of the lagoon surface was measured and found to be about one and one-half feet below sea level, and about 4 ft lower than the level of the lagoon to the S. W. about 100 yards away. There was clearly seepage of fresh water into our lagoon at the end--Philip Helfrich noticed an "oiliness" where the water was coming in. It is very likely therefore, that the effect exists only because of constant renewal by the incoming cold fresh water. We think that the effect probably dies out as one goes away from the end of the lagoon where we made our measurements. Thus, anomalous temperature structure is thought to be due to a very thin fresh water "blanket" that is renewed from seeps along the walls of the lagoon and prevents heat in the bottom layer from reradiating. To produce such a marked temperature change, this process must have been in operation for a good many years. Samples of this water have been sent to Philip Helfrich of the University of Hawaii for further analysis.

ATOLL RESEARCH BULLETIN

No. 90

Plants of Christmas Island

by

Alvin K. Chock and Dean C. Hamilton, Jr.

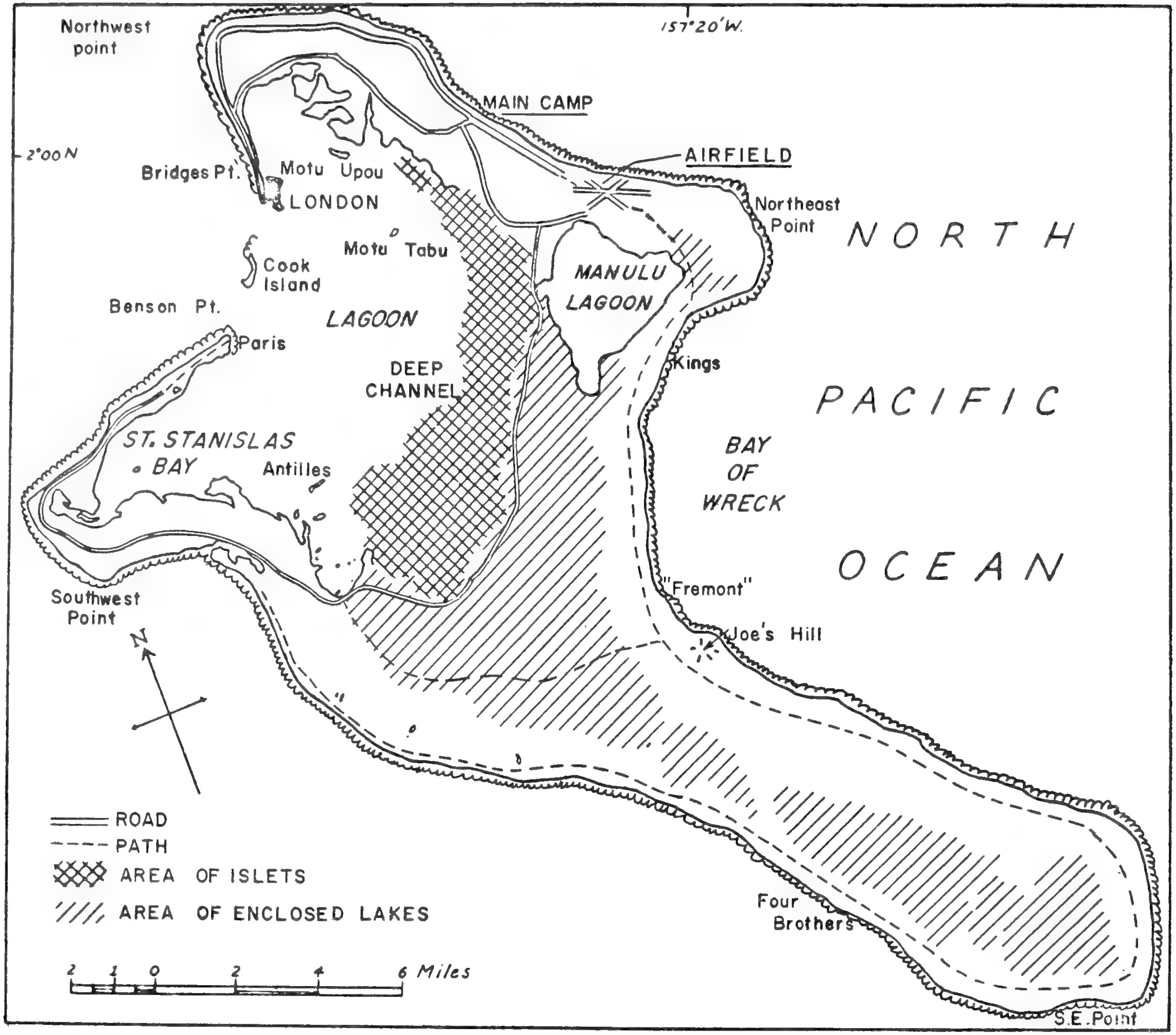
Issued by

THE PACIFIC SCIENCE BOARD

National Academy of Sciences--National Research Council

Washington, D. C.

December 15, 1962



SKETCH MAP OF CHRISTMAS ISLAND

Plants of Christmas Island[1]

by

Alvin K. Chock[2 & 3] and Dean C. Hamilton, Jr.[2]

During the period of April 11-14, 1962, the second author conducted an entomological survey of Christmas Island under the auspices of the Plant Quarantine Division, Agricultural Research Service, U. S. Department of Agriculture. In addition to the insect collections, 18 species of vascular plants were collected, and six additional cultivated ones were observed.

The collections were made on the northern portion of the island in the vicinity of the "Main Camp" and airport, as indicated on the map. The Division was primarily interested in the kinds of insects which would most likely hitch-hike on aircraft returning to Hawaii and which might be of potential agricultural significance. This area would also indicate recent accidental plant introductions. Due to the present use of the island for testing nuclear devices, no attempt was made to make collections elsewhere. Coconut is the only significant economic crop, and the plantations worked by Gilbertese natives would be areas of interest for future collecting.

Christmas Island was given its name because of its discovery on Christmas Day 1777, by Captain James Cook. During World War II it was one of the outposts of the Royal Air Force. This large coral atoll is located at 1°55'north latitude, 157°20' west longitude, and is part of the Pacific Equatorial or Line Islands. The island, with an area of 200 square miles, has an open salt water lagoon and many ponds of varying salinity; the highest elevation is 40 feet.

There was no basic change or difference in the character of the vegetation, from the beach inland, in the areas observed. The dominant species were Scaevola taccada (Gaertn.) Roxb. and Messerschmidia argentea (L.f.) Johnston occurring in clumps, with Pluchea odorata (L.) Cass. on the edges. Coconut trees were common on the northern coast and made up approximately one-third of the vegetation of the northwestern portion of the island.

Forty-one species of vascular plants have now been recorded from Christmas Island. New records of plants made as a result of this recent

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1. Approved for publication by the Director, Plant Quarantine Division, Agricultural Research Service, U. S. Department of Agriculture, Washington 25, D. C.

2. Plant Quarantine Division, Agricultural Research Service, U. S. Department of Agriculture, Honolulu, Hawaii.

3. Botany Department, Bernice Pauahi Bishop Museum, and Department of Botany, University of Hawaii, Honolulu, Hawaii.

collection are: Fimbristylis atollensis St. John, Artocarpus altilis (Park.) Fosb., two varieties of Hibiscus sp., Carica papaya L., Lycopersicon esculentum Mill., and Pluchea indica (L.) Less.

The first significant botanical survey of Christmas Island was made in August 1924 by the Whippoorwill Expedition of the Bishop Museum. Plant collections totaling 24 species plus two additional ones observed were made by Erling Christophersen (1927) and H. F. Bergman. G. P. Wilder also collected there in December of the same year. In October 1934, three additional species were recorded from collections made by Harold St.John, C. Montague Cooke, Jr., and F. Raymond Fosberg. Five additional new records were established in the August 1936 collections of Fosberg (1939, 1943), Alfred Metraux and E. M. Metraux.

No additions from Christmas Island were made to the Bishop Museum's Herbarium until October 1958, when Major M. D. Gallagher of the Royal Air Force Natural History Society (Christmas Island) sent specimens for determination to Mr. E. H. Bryan,Jr. They were identified by Miss Marie Neal, and the identifications published by the Society (1959).

The authors would like to acknowledge the cooperation and courtesies extended by Joint Task Force 8 during the recent trip, and the Christmas Island map supplied by Mr. Bryan, which was redrawn by Miss Yona Bielefeldt. [For technical reasons, another map had to be substituted.--Eds.]

All the collections cited in the checklist below are deposited in the Herbarium of the Bishop Museum. Collection numbers follow the collector's initials, as indicated below:

EAB	E. A. Bessey
HFB	E. F. Bergman
EC	E. Christophersen
DCH	Dean C. Hamilton,Jr.
CPW	Gerritt P. Wilder
FRF	F. R. Fosberg
FRF & AM	Fosberg & A. Metraux
FRF & EMM	" & E. M. Metraux
RAF	RAF Nat. Hist. Soc. (Gallagher)
St.J & CMC	St. John & C. M. Cooke,Jr.
St.J.& FRF	St. John & Fosberg

Fungi imperfecti

These were found and determined by E. A. Bessey on the indicated gramineous host collections.

Phoma sp.
EAB 762, on Eragrostis amabilis (FRF 13229)
Cladosporium sp.
EAB 760, on Eragrostis whitneyi (FRF 13230)
Curvularia lunata (Wakker) Boed.
EAB 757, on E. whitneyi (HFB 14)
Diplodia sp.
EAB 757, on E. whitneyi (HFB 14)
Heterosporium sp.
EAB 756, on E. whitneyi (FRF 13230)

Pandanaceae

Pandanus tectorius Sol.
HFB 32

Gramineae

Cenchrus echinatus L.
DCH 2

Digitaria pacifica Stapf.
Syntherisma pelagica F.Br. var. F.Br. (HFB 7, type)
HFB 7; StJ & FRF 17492; FRF & AM 13218, 13231, 13265.
Plants identified as Panicum stenotaphroides Nees by Christophersen (1927, p. 22) belong here (cf. Fosberg 1939)

Eleusine indica (L.) Gaertn.
DCH 17

Eragrostis amabilis (L.) W.& A.
HFB 15; FRF 13229

E. whitneyi Fosberg var. whitneyi
FRF 13195 (type), 13230, 13266; HFB 14; StJ & FRF 17489
Plants identified as E. falcata (Gaud.) Gaud. by Christophersen (1927), and as E. paupera Jedwabnik by J. R. Swallen belong here (Fosberg 1939)

Lepturus repens (Forst.) R. Br.
HFB 1; StJ & CMC 17481; FRF & AM 13196, 13206; DCH 11

Cyperaceae

Cyperus rotundus L.
FRF 12172, 13282

Fimbristylis atollensis St. John
DCH 1

Palmae

Cocos nucifera L.
Christophersen (1927, p.22) says "about 300,000 trees, almost all of which have been planted. Chief plantations are at 'London' and northwards, 'Poland' and 'Rapa.' Smaller plantations are scattered."

Moraceae

Artocarpus altilis (Park.) Fosb.
DCH was told of 4 small cultivated trees in the Resident Commissioner's residence.

Nyctaginaceae

Boerhavia repens L.
StJ & CMC 17484, 17482; RAF D; DCH 9; HFB 10a; StJ & FRF 17495 (identified as B. diffusa var. pubescens (R.Br.) Choisy)
Plants identified as B. hirsuta L. by Christophersen (1927, p. 23)

belong here. Fosberg examined the Boerhavia material in the Linnean Herbarium, and found that the specimens of B. repens are similar to the plants with mostly axillary cymes found in the Pacific. B. diffusa, on the other hand, seems to be the paniculate one which is a common weed in Ceylon and other Asiatic areas. The latter name, however, has been used by most Pacific authors for this plant.

Boerhavia tetrandra Forst.
HFB 9, 10b, 11; GPW

Pisonia grandis R. Br.
HFB 8; StJ & CMC 17479

Aizoaceae

Sesuvium portulacastrum L. var. griseum Degener & Fosberg
HFB 13; StJ & FRF 17493; DCH 12
Called S. portulacastrum by Christophersen (1927)

Portulacaceae

Portulaca fosbergii von Poellnitz
FRF 13269; DCH 16

P. johnii von Poelln.
StJ & CMC 17478. This collection needs further study

P. lutea Sol.
HFB 4; GPW; FRF 13188; FRF & AM 13220, 13223; RAF I, S, R; DCH 14

Lauraceae

Cassytha filiformis L.
HFB 34; FRF & AM 13213, 13235; RAF M; DCH 7

Cruciferae

Lepidium bidentatum Mont.
EC 48 (identified as L. owaihiense C.& S. in Christophersen 1927,p. 24)

Leguminosae

Erythrina variegata var. orientalis (L.) Merr.
E. indica Lam.
This species cultivated on the island according to Christophersen (1927).
No specimens were collected.

Leucaena leucocephala (Lam.) de Wit
FRF 13249

Phaseolus lathyroides L.
FRF 13272

Zygophyllaceae

Tribulus cistoides L.
HFB (EC) 23; RAF G; DCH 13

Simarubaceae

Suriana maritima L.
HFB 5; GPW 6; StJ & CMC 17480; FRF 13192, 13264; FRF & AM 13217; RAF C; DCH 18

Euphorbiaceae

Euphorbia hirta L.
HFB 19; FRF 13268; FRF & EMM 13248

Phyllanthus amarus Sch. & Thonn.
HFB 16; FRF 13276

Malvaceae

Abutilon albescens Miq.
FRF & AM 13215. Wrongly identified as A. indicum Sweet (Fosberg 1943, p. 397), re-identified by Fosberg, 1962.

Hibiscus tiliaceus L.
HFB 17; FRF 13267; DCH 15. According to Christophersen (1927, pp.27,77) and Fosberg (1943, p. 397) this species is cultivated on Christmas I.

Hibiscus sp.
DCH observed two different varieties (one plant each) with pink flowers

Sida fallax Walp.
HFB 3, 21; FRF 13191, 13283; FRF & AM 13210; FRF & EMM 13225; DCH 6. Plants listed as S. cordifolia L. in Christophersen 1927, p. 26, belong here.

S. rhombifolia L.
HFB 18

Caricaceae

Carica papaya L.
DCH observed two cultivated trees near the airport.

Boraginaceae

Heliotropium anomalum H. & A. var. mediale Johnston
HBF 2; GPW 7; StJ & FRF 17486 (type), 17487, 17488, 17494; FRF & AM 13209; FRF 13190, 13232, 13273, 13274; RAF H, O_1 , O_2; DCH 3. Listed as H. anomalum H. & A. by Christophersen 1927.

Messerschmidia argentea (L.f.) Johnston
Tournefortia argentea L.f.
HFB 6; StJ & CMC 17477; FRF 13189; FRF & AM 13219; RAF A; DCH 5

Solanaceae

Lycopersicon esculentum Mill.
DCH observed 4 cultivated tomato plants near the airport

Rubiaceae

Hedyotis romanzoffiensis (C. & S.) Fosberg
Kadua romanzoffiensis C. & S.
Gouldia romanzoffiensis (C. & S.) A. Gray
HFB 12; StJ & FRF 17491; FRF 13194, 13234, 13284

Goodeniaceae

Scaevola taccada (Gaertn.) Roxb.
HFB 20; StJ & FRF 17496; FRF & AM 13216; FRF 13233; DCH 10. Wrongly called S. frutescens (Mill.) Krause in Christophersen 1927, p.27.

Compositae

Pluchea indica (L.) Less.
DCH 8

P. odorata (L.) Cass.
RAF J; DCH 4

Vernonia cinerea Lessing
HFB 22

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ATOLL RESEARCH BULLETIN

No. 91

Central subsidence. A new theory of atoll formation

by

Hans Hass

Issued by

THE PACIFIC SCIENCE BOARD

National Academy of Sciences--National Research Council

Washington, D. C.

December 15, 1962

Central subsidence. A new theory of atoll formation [1]

by

Hans Hass [2]

Introduction

The Xarifa-Expedition to the Maldives and Nicobars in 1957/58 was an undertaking of the International Institute for Submarine Research at Vaduz, Liechtenstein, a private foundation of mine. It was partially sponsored by the Max Planck Gesellschaft at Goettingen and the Ministry of Culture of North Rhine-Westfalia. I had hoped that the main part of the costs would be contributed by the Deutsche Forschungsgemeinschaft; unfortunately this was not possible and I therefore covered the costs by producing 26 television programs for the BBC and German television. It had been my intention to investigate the development of atoll formation, as I hoped that underwater investigations in the Maldives might perhaps throw light on this still obscure problem. In the circumstances, however, my time was almost entirely absorbed by film work and the management of the expedition. For this reason the following arguments can only be substantiated in a very general way. As I see no opportunity to carry on this research in the near future, and as my theory may perhaps give others a lead, I decided to publish the following short account from my book "Expedition ins Unbekannte" published by Ullstein, 1961. This book will eventually be translated into English and published by Hutchinson, London; it also includes a list of the scientific papers giving the results of this expedition.

Atoll formation

Darwin considered that some of the islands surrounded by coral reefs had subsided in the course of time until finally they had disappeared completely beneath the surface of the sea, and that at the same time the original fringing reef had grown higher and higher until it finally remained as a ring in the sea.

On the other hand, Murray and others have explained the formation of atolls by a rise in the ocean bed. In this way a rise of the bed to within perhaps 50 meters of the surface would be followed by the onset of

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1/ Ergebnisse der Xarifa-Expedition 1957/58.
2/ Internationales Institute für Submarine Forschung.

Note. We are publishing this paper in spite of the negative reactions of some of our advisors, not because it represents in any way the conclusions of the Pacific Science Board Coral Atoll Program, or of the editors, but because it is the editorial policy of the Atoll Research Bulletin not to suppress ideas that arise from field observation. It must be pointed out that the observations suggest that the structure of Maldivian atolls must be very different from that of the Central Pacific Atolls with which we are familiar.--Eds.

growth in reef-building corals. As conditions would be more favorable on the outer edge, there would be greater growth there, and so a ring would be formed.

A third theory (Daly) is based on the fall of the sea level during the last Ice Age and the subsequent cooling of the water. This would have caused the death of the corals followed by wave erosion of the reefs, leaving large, bare platforms. When the sea rose again and the water grew warmer, new coral growth would have begun, principally on the outer edges, and so the familiar ring would have been formed.

An aerial survey of the reefs in the Maldives has suggested to me quite a different theory. All stages of development can be seen here. Firstly, isolated cone-like growths appeared and just reached the surface. There were also larger growths in which the centers had sanded over, though coral still appeard to be growing strongly on the outer edges. Finally, there were the typical reef rings surrounding beautiful blue lagoons (figs. 1-5). The depth of the lagoons seemed to bear a direct relationship to the size of the atoll: the larger the reef, the deeper the blue of the lagoon. It occurred to me that the rising and extending reefs first became barren in the middle and then subsided in the center like a piece of cake. The farther they extended outwards the more they sank in the middle.

Subsequent underwater investigations showed that this first impression of an uninterrupted transition from a small coral reef to an atoll was not mistaken, and led me to an observation which throws new light on the old problem. I discovered, in fact, that the inner structure of these reefs is by no means as firm and solid as has been assumed. They are actually built by very delicate, much branched corals, such as Acropora and Echinopora which grow up over each other to form a kind of loose scaffolding (figs. 6, 7). When the coral dies, fragments break off and roll down to form a slope of loose debris extending into deep water at an angle of about 45° (fig. 8).

At a depth of about 18 meters, I tried to drive a tunnel into the side of the reef, and found this quite easy to do, even with my bare hands. The structure was, however, so loose and shifting that it soon became undermined and collapsed.

These facts suggest a simple explanation to account for the formation of atolls. As the reef rises and extends outwards on all sides by growth and the accumulation of debris, the lattice work of corals which was at first on the outside becomes part of the inside of the reef and thus subject to the weight of the debris lying above. In the course of time, the calcareous material becomes brittle, possibly even re-crystallizes, and thus causes the originally loose structure to collapse under the pressure from above. This process obviously bears some relationship to the age of the reef itself, as one can see very clearly in the Maldives. With a ring diameter of about 2 km, the depth of the lagoon is between 10 and 20 meters; a diameter of 8 km gives a depth of up to 40 m, a diameter of 24 km a depth of 70 m, and so on.

As other observers have mentioned, the lagoon itself does not fill up again with corals because the environmental conditions there are unfavorable for their growth. We were able to follow this general process very closely in the Maldives (figs. 2-4). As soon as a reef reaches the surface and begins to spread out in all directions, a barren area forms in the middle, something like a bald head. Here there is a double relationship between cause and effect. The more favourably placed corals flourishing on the outer edge take a greater share of the available oxygen and food, with the result that the corals growing in the middle gradually perish and crumble, forming coral sand. This sand is then swept backwards and forwards by the tides and so helps to smother the surviving corals. In this way a reef with a diameter of perhaps not more than 300 m will become a miniature atoll with a center growing progressively barer and at the same time starting to subside.

The rate of subsidence is probably influenced by the particular solidity of the upper part of the reef, the so-called reef flat. This firmness is due chiefly to calcareous algae which live only in shallow water. They cover all the coral fragments with a crust and join them firmly together so that--as the reef extends--a solid platform develops resting on the porous mass below (fig. 10, A, B). Only when this platform has reached a certain size and has become barren and sandy in the center does subsidence set in (fig. 10, C, D). This suggests that possibly the center of the platform, when it becomes barren and covered with sand, somehow disintegrates and loses some of its firmness.

Another point may also play a part here: the larger the atoll, the greater the volume of water enclosed in relation to the circumference of the reef. It must be remembered that whereas the circular reef merely extends in one dimension by an increase in circumference, the enclosed water increases by the square. More outlets thus become necessary to allow the tidal water to flow in and out of the atoll. At ebb tide the water is trapped inside the atoll, and until it finally manages to flow out its level is a little higher than that of the surrounding sea (fig. 11). This means that for some time there is a greater pressure on the bed of the lagoon, and it is quite possible that in the course of thousands of years this constantly changing tidal pressure may influence the subsidence of the lagoon bed, by a kind of rhythmic massage.

It may seem that this idea is incompatible with the porous structure of the reef as described above, but here again the firmness of the reef flat must be considered. The reef flat represents a more or less impervious bottom resting--after subsidence--like a cup on top of the porous structure. From time to time sudden tropical rainstorms may also increase the volume and weight of the trapped water. In this way a downward pressure is exerted.

Only as the atoll grows and channels appear in the ring will the conditions for coral growth in the lagoon again improve progressively. Secondary fringing reefs will then form along the inner margin of the atoll, causing a considerably steeper slope (fig. 12, F), and secondary cone-like reefs will grow up from the lagoon bed (fig. 12, R). This completes the chain of development which is typical of the Maldives. The

secondary lagoon reefs experience, of course, the same extension and subsequent central subsidence, and this explains the presence of small rings within the larger ones (figs. 9 and 12 A).

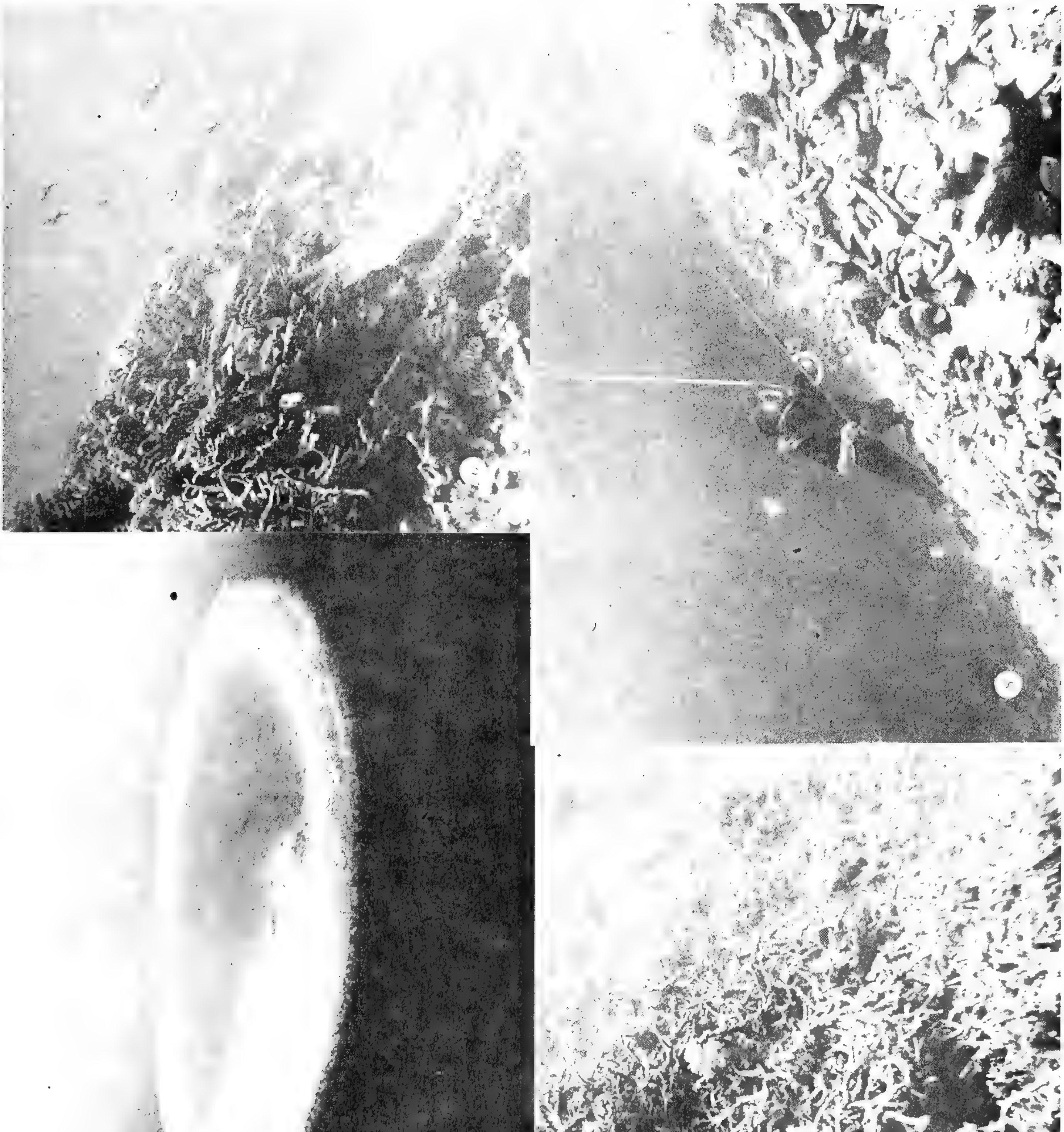
The theory put forward here also accounts for the formation of barrier reefs. If a fringing reef continues to extend towards the sea, then, by the same reasoning, the rear section gradually subsides and a deepening lagoon is formed between the land and the reef. The theories of upheaval and abrasion do not sufficiently explain the fact that the larger the atolls are, the deeper they become, and also the lagoons of barrier reefs become deeper as the reef extends farther out from the land. The present theory, on the other hand, gives an explanation of both these phenomena.

Few theories have accounted for the fact that atolls exist only in certain tropical areas. My answer to this problem is simply that the reefs are not everywhere built by the same kinds of coral.

The particular firmness and solidity of the upper part of the reef has, in my view, led to a misunderstanding. Scientists who have not had the opportunity to dive have been misled by this solidity of the reef flat to assume that its inner structure was similarly firm. In the Red Sea, where the more compact Porites corals play a greater part in the building of the reefs, this may well be so, but this is not so in the case of the Maldive reefs. Here too the platform spreads out like a solid mass of concrete, but the foundation on which it rests is loose and porous. The fact that it takes a long time before this platform actually subsides in the middle may be due to static factors and to a natural disintegration of the material in the center.

Whether this theory of central subsidence satisfactorily accounts for every known ring formation is another matter. As Hoffmeister and Ladd have pointed out, it is possible that not all atolls have been formed in the same way. Some may have come about through the rise or fall of the ocean bed, and others through ice age abrasion. However, amongst the various possibilities I feel that the present theory is entitled to some consideration, particularly as it has in fact the advantage that it does not rely on either a rise or a subsidence in the ocean bed or on a fall in the sea level, but explains the origin of both atolls and barrier reefs from the normal processes of coral growth.

Summary: Reefs built mainly by slender branching corals have a porous and unstable inner structure. This causes the more extensive reef flats to subside in the center. Such central subsidence may possibly be further influenced by re-crystallization of the underlying material, by the disintegration of the material of the center of the reef flat itself, and by the cumulative effect of changes in water pressure in the lagoon caused by the tides and occasional rainstorms.



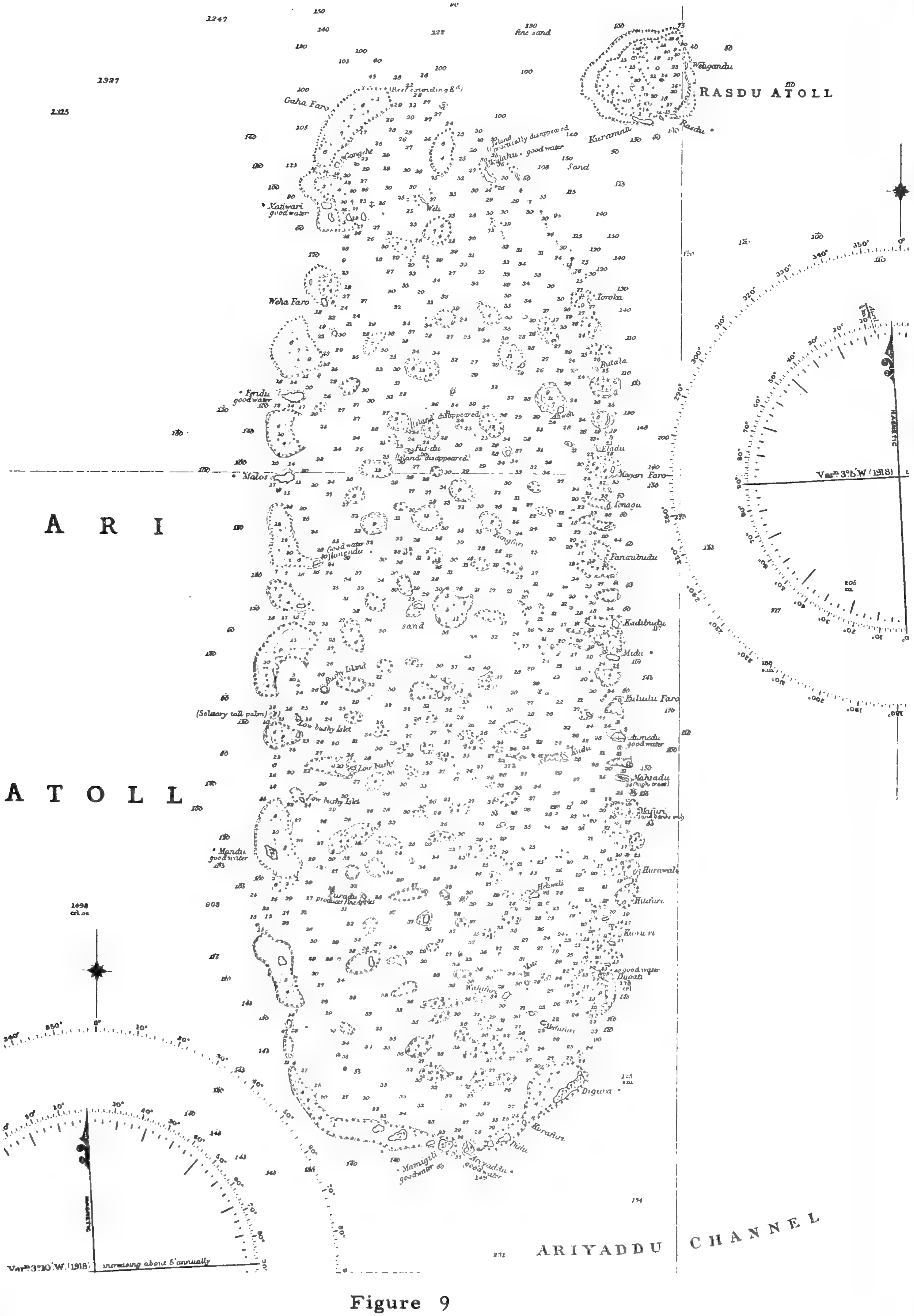

RASDU ATOLL
ARI
ATOLL
ARIYADDU
CHANNEL
Var^n 3°5' W. (1918)
Var^n 3°10' W. (1918) increasing about 5' annually
Gaha Faro
Weha Faro
Malos
Digura
Rasdu
Kuramati
Maaya Faro
Kuludu Faro
Mandu good water
Fendu good water
Mamigili good water
Ariyaddu good water

Figure 9

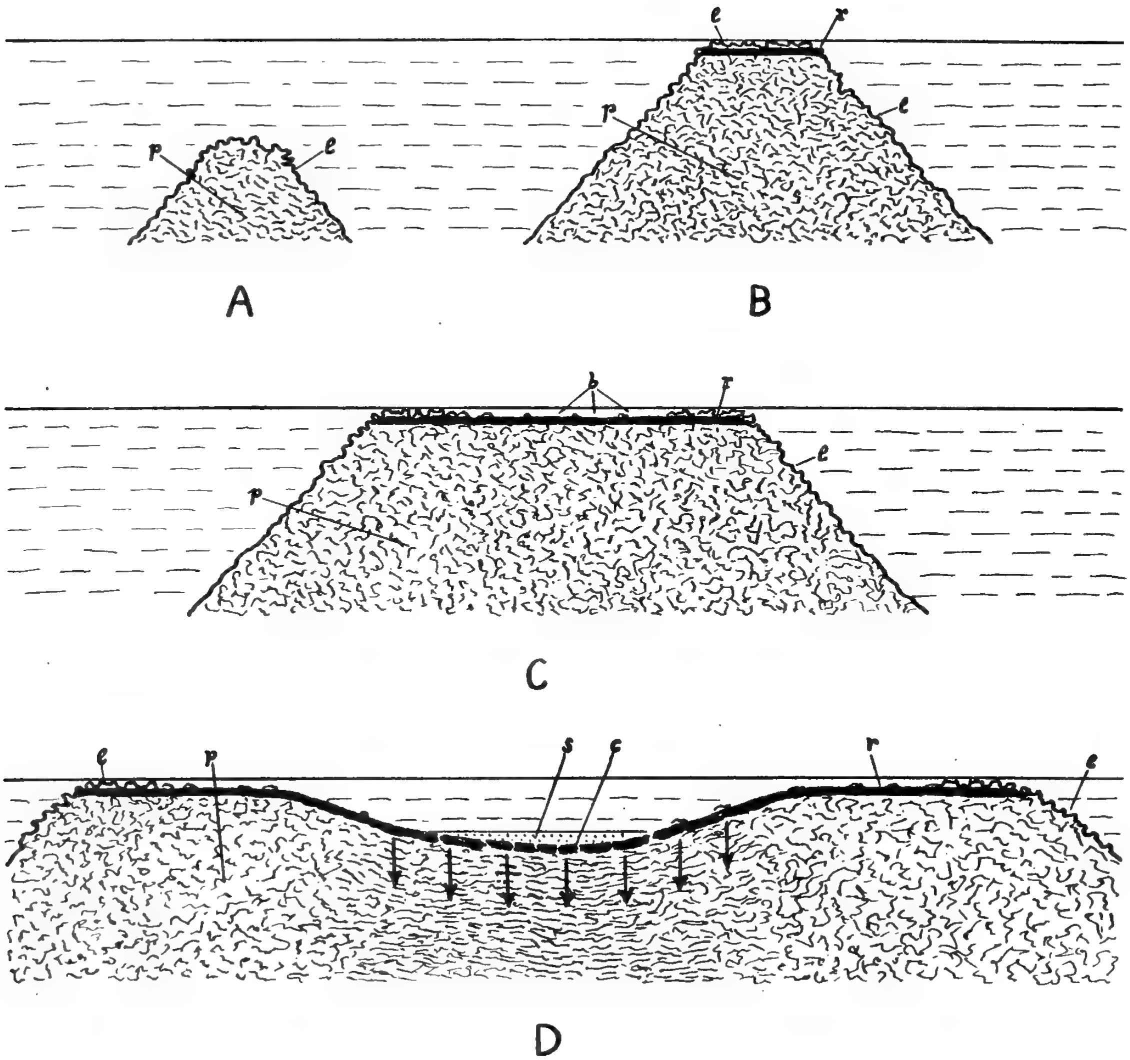


Fig. 10: Schematic sections through a reef gradually turning into an atoll. A) a cone-like reef grows toward the surface. B) Reaching the surface, the reef forms a solid reef flat. C) Reef and reef flat extend outwards, the center of the platform gets barren and covered with sand. D) The reef has further increased in size and the platform subsides at the center.

l = living coral — b = barren area partly covered with sand
p = porous structure — s = sand and gravel
r = reef flat — c = central part of the platform which possibly disintegrates

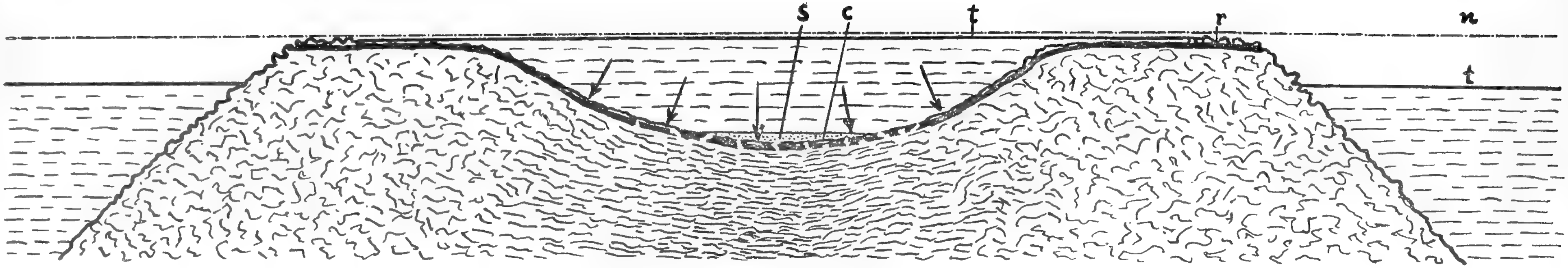


Fig. 11: Schematic section through an atoll showing the downward pressure of the water trapped at low tide.
n = normal sea level
t = sea level at low tide
r = reef flat
s = sand and gravel
c = central part of the platform which possibly disintegrates

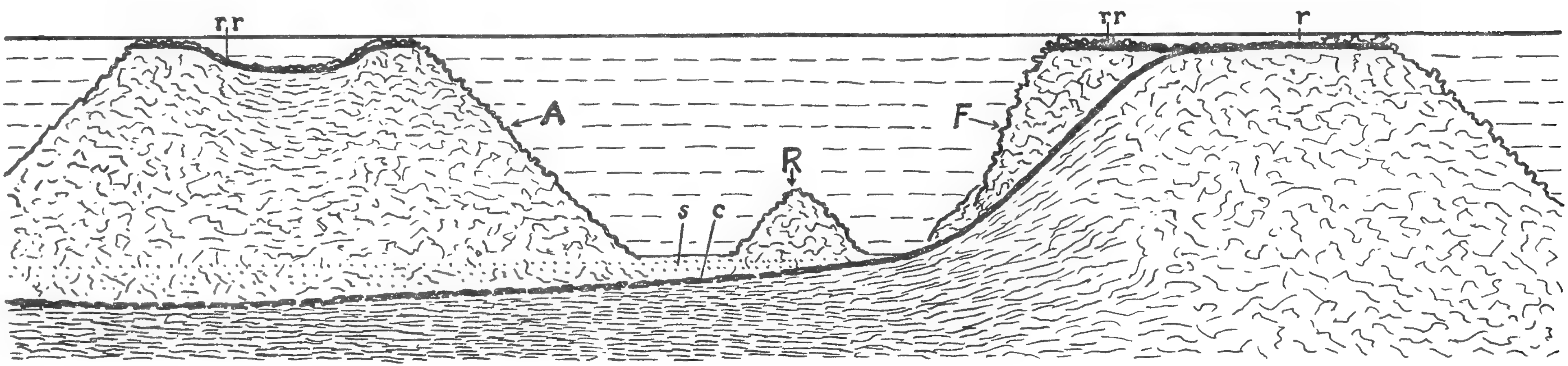


Fig. 12: Schematic section through one side of a larger atoll showing development of secondary fringing reef (F), secondary cone-like reef (R), and further development of such cone-like reef into a small secondary atoll within the large atoll (A).
r = reef flat
s = sand and gravel
c = central part of the platform which possibly disintegrates
rr = secondary reef flats

ATOLL RESEARCH BULLETIN

No. 92

Vascular plants recorded from Jaluit Atoll

by

F. R. Fosberg and M.-H. Sachet

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Vascular plants recorded from Jaluit Atoll

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During the German occupation of the Marshall Islands (1885-1914) Jaluit was the seat of colonial government and the principal German settlement. Many plants were brought in for trial and many were introduced accidentally. At Jabor a small botanical garden was maintained. This was continued during the Japanese regime (1914-1944) and revived as an agricultural experiment station by the Trust Territory administration (1955-1958). Soil was brought in from high islands, and with this help and in an extremely wet climate plants survived that would not normally be expected to on a low coral island.

A number of accounts of the plants of Jaluit were published by German and Japanese authors, and Jaluit specimens are cited in several taxonomic papers.

Mr. J. Boyd Mackenzie, director of the experiment station from 1955 until its destruction in 1958 by typhoon Ophelia I (see Atoll Res. Bull. 75), prepared a manuscript list of plants observed by him, to which he kindly gave us access. B. C. Stone made available a list compiled by him, largely based on St. John's observations. Collections have been made in Jaluit by Betche in 1888 (seen at the Sydney Herbarium), Schnee in 1901 and 1902 (also at Sydney), Koidzumi in 1915 (seen at Tokyo University Herbarium), St. John in 1946 (seen at the Bishop Museum), Lyman in 1946 (deposited in the U. S. National Herbarium) and Fosberg in 1946, 1958, 1960 (also in the U. S. National Herbarium). Other collections have been made but we have not seen any material from them.

No thorough investigation of the flora, especially of the cultivated flora, was published after the Okabe list of 1941 and before 1958, though several large collections were made. Thus it is not certain which of the cultivated species reported earlier and found missing in 1958 and 1960 simply had not survived the normally unfavorable atoll environment and which were eliminated by Typhoon Ophelia I, in January 1958. Those reported by Mackenzie may be presumed to have survived until the time of the 1958 typhoon, though exact records supported by specimens are lacking, and some of the identifications are doubtful. A tabular account of species and their occurrence on islets examined before and after the typhoon was included in Atoll Research Bulletin 75: 96-105, 1961.

Since most of the pre-World War II introduction of plants to the Marshall Islands took place through Jaluit, it seems desirable to prepare a list of all the vascular plants reported from the atoll. This should be of interest in tracing the spread of certain introduced species, in estimating the chances of survival of introductions, and in recording what is there now, as well as in providing an account of the known indigenous species. This list is based on (1) earlier published records, (2) specimens examined by us, and (3) sight records by St. John, Mackenzie, and Fosberg, when no specimens were available.

Names of species not known to exist on the atoll at present are enclosed in parentheses.

The botanical names used are those now believed to be correct. The names used by earlier authors, if different, are referred to with the records by these authors. Some of these are synonyms, others probably misidentifications. English vernacular names are preceded by (E), Marshallese names by (M). The Marshallese names are those generally used or reported from the Marshall Islands, not necessarily recorded in Jaluit.

Numbers of specimens collected by St. John are preceded by S, those collected by Fosberg by F. Other collectors' names are spelled out. The following symbols are used before the plant names:

# indicates that the species is of probable aboriginal introduction
* post-European introduction
c cultivated or planted
p persisting from cultivation

The two last are not always sharply distinguished. If a name has no symbol the plant may be regarded as indigenous.

PSILOPSIDA

Psilotum nudum (L.) Beauv.

Okabe (1941).

FILICES

Ophioglossaceae

Ophioglossum pendulum L.

F 41409. Epiphyte, rare on Jaluit, found only in wet forest in interior of Pinlep Islet.
(M) Nin in nonep.

Polypodiaceae (sensu lato)

(c* Alsophila sp.)

Seen by Mackenzie.
This record seems unlikely, but it is hard to guess what the plant was.

Asplenium nidus L.

Volkens (1903).
S 21695; F 26740. Common on less disturbed islets, usually terrestrial, abundant on ground in interior of Ribon Islet.
(M) Kartep; (E) Birdsnest Fern.

Nephrolepis acutifolia (Desv.) Christ

Volkens (1903); Okabe (1941) as N. acuta Presl.
S 21679; F 26741, F 26772; F 39422, F 39441; "Jaluit and Ebon" Betche 3. Generally epiphytic, usually on mangroves.
(M) Iri, Anomkadede.

(c* Nephrolepis biserrata var. furcans Hort.)

Seen by Mackenzie.
(E) Fishtail fern.

Nephrolepis hirsutula (Forst. f.) Presl.

Volkens (1903), Koidzumi (1915, 1917), Kanehira (1935); Okabe (1941) all as N. exaltata Schott.
S 21677; F 26737, F 39435, F 39440. Occasional in shade on most islets, terrestrial.
(M) Iri (jide, ide)

Polypodium scolopendria Burm. f.

Volkens (1903), Koidzumi (1915, 1917), Kawagoe (1917), Kanehira (1935), Okabe (1941) all as P. phymatodes L.
Schnee in 1901, Schnee in 1902; F 26746, F 26757. Common generally, terrestrial.
(M) Kino.

Pteris tripartita Sw.

Volkens (1903); Okabe (1941) as P. wallichiana Ag.
S 21663; F 26751. Not common, terrestrial.
(M) Iiri pairik

Thelypteris goggilodus (Schkuhr) Small

F 41405. Common in taro pits on Pinlep Islet.

Vittaria incurvata Cav.

Okabe (1941) as V. elongata Sw.
S 21681; F 26745, F 39444, F 41392, F 41413. Rare, epiphytic.
(M) Wujoet, Ujooj; (E) Shoestring fern.

SPERMATOPHYTA (Seed Plants)

Cycadaceae

c* Cycas circinalis L.

Volkens (1903) as C. sp.; Koidzumi (1917); Okabe (1914) as C. rumphii Miq.
Lyman 4. Planted at Jabor
(E) Cycad, Sago palm.

(c* Cycas revoluta Thunb.)

Okabe (1941).
(E) Cycad, Sago palm.

Pinaceae

(c* Pinus thunbergii Parl.)

Okabe (1941).
(E) Japanese black pine.

Araucariaceae

(c* Araucaria excelsa R. Br.)

Volkens (1903), Koidzumi (1917).
(E) Norfolk Island Pine.

Hydrocharitaceae

Thalassia hemprichii (Ehrenb.) Asch.

F 39467. Found in shallow water in the edge of the lagoon at Pinlep Islet.
(E) Turtle grass.

Pandanaceae

Pandanus tectorius Park.

Engler (1897) as P. utilis Bory; Schumann & Lauterbach (1901), Volkens (1903) both as P. fascicularis Lam.; Koidzumi (1915, 1917) as P. tectorius var. pulposus Warb.; Kawagoe (1917) as Pandanus sp.; Kanehira (1935, 1936) as P. jaluitensis Kaneh., P. lakatwa Kaneh., P. laticanaliculatus Kaneh., P. laticanaliculatus var. edulis Kaneh., P. macrocephalus Kaneh., P. menne Kaneh., P. obliquus Kaneh., P. pulposus (Warb.) Mart., P. trukensis Kaneh. and P. trukensis var. agiwarok Kan., Okabe (1941) (as various species).
S 21701, S 21902, S 21703; F 26759, F 26766, F 26779, F 41396. A common and important tree, very variable and with many cultivars recognized and used by the Marshallese, as well as wild forms and segregates.
(M) Bop (Bob); (E) Pandan, Screw Pine.

Gramineae

(c* Bambusa glaucescens (Willd.) Sieb. ex Munro)

Okabe (1941) as B. nana Roxb.
(E) Dwarf bamboo, hedge bamboo.

(c* Bambusa blumeana Schultes)

Volkens (1903), Koidzumi (1917) both as B. arundinacea Willd.
(E) Spiny bamboo.

*Cenchrus echinatus L.

Volkens (1903), Koidzumi (1915, 1917), Kanehira (1935), Okabe (1941) all as C. calyculatus Cav.
F 26712. Very common in open areas.
(M) Leklek; (E) Sandbur.

(#Centotheca lappacea (L.) Desv.)

Volkens (1903).
Common in the Carolines, on high islands, but otherwise unknown in the Marshalls.
(M) Ujoj (udjodj).

(*Cymbopogon citratus (DC.) Stapf)

Okabe (1941).
(E) Lemon grass.

*Cynodon dactylon (L.) Pers.

Seen by Fosberg. Established on Majurirek Islet.
(E) Bermuda grass.

(*Dactyloctenium aegyptium (L.) Willd.)

Okabe (1941)
(E) Crowfoot grass.

(*Digitaria ciliaris (Retz.) Koel ?)

Volkens (1903) as Panicum sanguinale L.; Kanehira (1935), Okabe (1941) both as Syntherisma sanguinalis (L.) Dulac;
Very possibly a misidentification of the following species, though most records of D. sanguinalis in the tropics are D. ciliaris.
(E) Crabgrass.

Digitaria pruriens var. microbachne (Presl) Fosb.

Koidzumi (1915, 1917) as Panicum sanguinale.
Koidzumi in 1915; Schnee 31; F 26704, F 39459, F 41401. Occasional generally, in sun or shade.
(E) Crabgrass.

Echinochloa crus-galli var. crus-pavonis (H.B.K.) Hitchc.

F 39464, F 41407. Found only in the taro pits on Pinlep Islet, but abundant there.

*Eleusine indica (L.) Gaertn.

Volkens (1903); Okabe (1941).
F 26701. A very common ruderal species.
(M) Katejukjuk; (E) Goose-grass

*Eragrostis amabilis (L.) W. & A.

Okabe (1941) as E. plumosa L.
Schnee 109; Betche 13; F 26695. Ruderal around villages.
(E) Love-grass.

(*Eragrostis ciliaris (L.) R. Br.).

Volkens (1903); Koidzumi (1915, 1917).

Lepturus repens (Forst. f.) R. Br.

Koidzumi (1917); Kanehira (1935) as Monerma repens (Forst.) Beauv.; Okabe (1941).
Very general, widespread in atolls.
(M) Ujooj-bukor.
Two varieties have been collected in Jaluit:
var. septentrionalis Fosb.
F 26694, F 41416 (towards var. subulatus), F 41417.
var. subulatus Fosb.
F 41415.

(c* Miscanthus sinensis Anders.)

Okabe (1941).

*Paspalum conjugatum Bergius

F 39462. Found in the village on Pinlep Islet in 1958.
(E) Hilo grass.

*Paspalum distichum L.

F 39456. Found on Jabor in 1958.
(E) Salt grass.

(*Saccharum officinarum L.)

Volkens (1903), Okabe (1941).
(E) Sugar cane.

p*Sorghum bicolor (L.) Moench

S 21673; F 26705. Still found in 1958.
(E) Sorghum; (M) Korn.

(*Stenotaphrum secundatum (Walt.) O. Ktze.)

Schumann (1888), Schumann & Lauterbach (1901), Volkens (1903), Koidzumi (1915, 1917) all as S. americanum Schrank.
(E) St. Augustine grass.

Thuarea involuta (Forst. f.) R. & S.

Volkens (1903) as T. indica Gaertn.; Koidzumi (1915, 1917), as T. sarmentosa; Okabe (1941).
F 26713. Generally distributed.

c*Zoysia tenuifolia Willd. ex Trin.

F 41408. Planted on Pinlep in village, supposed to have been brought from Jabor where it was introduced by the Japanese.
(E) Japanese grass.

Cyperaceae

(c*Cyperus alternifolius L.)

Seen by Mackenzie
(E) Umbrella plant.

(*Cyperus brevifolius (Rottb.) Hassk.)

Okabe (1941) as Kyllinga brevifolia Rottb.

*Cyperus compressus L.

Kükenthal (1924, 1935); Kanehira (1935).
F 39474. Found only on Jabor.

Cyperus javanicus Houtt.

Volkens (1903) as C. pennatus Lam.; Koidzumi (1915, 1917), Okabe (1941) both as Mariscus albescens Gaud.; Kanehira (1935), Kükenthal (1936), both as Mariscus pennatus (Lam.) Merr.
F 26706. A widespread atoll species, found occasionally in moist places.
(M) Ujooj in ion bwil.

*Cyperus kyllingia Endl.

Volkens (1903), Kükenthal (1924) both as Kyllinga monocephala Rottb.; Kükenthal (1935).
F 26697, F 41400. Found only on Jabor.

*Cyperus odoratus L.

F 39465. Found only in taro pits on Pinlep Islet.

*Cyperus rotundus L.

Kükenthal (1924, 1935); Kanehira (1935); Okabe (1941).
F 39478a. Found in village in Jabor, much more abundant in 1960 than in 1958.
(E) Nut-grass.

Eleocharis geniculata (L.) R. & S.

(E) Spike-rush.
F 39466. Found only in taro pits on Pinlep Islet.

Fimbristylis cymosa R. Br.

Volkens (1903) as F. glomerata (Retz.) Nees; Koidzumi (1915, 1917) as F. wightiana Nees; Kanehira (1935) as F. spathacea Rottb.; Okabe (1941) as F. cymosa R. Br. and F. spathacea Rottb.
Betche 184; Schnee 42.K; F 26715, F 41414. A widespread strand plant, the atoll form regarded as a separate species, F. atollensis, by St. John.
(M) Perelijman, padalijmaan.

Palmae

(C*Areca catechu L.)

Volkens (1903).
(E) Betel nut.

(C* Caryota urens L.)

Okabe (1941).
(E) Wine palm, fish-tail palm.

c#Cocos nucifera L.

Volkens (1903), Koidzumi (1915, 1917), Kawagoe (1917), Okabe (1941).
F 39454. The most abundant tree, planted generally on all except the tiniest islets.
(E) Coconut; (M) Ni (with many other names applying to different varieties, stages of maturity and parts of the plant).

(c*Corypha umbraculifera L.)

Seen by Mackenzie.
This record seems unlikely and may be based on a faulty identification; according to Mackenzie (conversation, 1958) it may have been Phoenix canariensis.

(c*Elaeis guineensis Jacq.)

Okabe (1941).
(E) African oil palm.

(c* *Livistona* sp.)

Okabe (1941).

(c**Phoenix canariensis* Hort. ex Chabaud)

Seen by Mackenzie.
(E) Canary Island palm.

(c**Phoenix dactylifera* L.)

Okabe (1941).
(E) Date palm.

(c**Pritchardia pacifica* Seem. and Wendl.)

Koidzumi (1917); Mackenzie as *P. aurea*.

(c**Rhapis flabelliformis* Ait.)

Okabe (1941).

Cyclanthaceae

(c**Carludovica palmata* R. and P.)

Okabe (1941).
(E) Panama hat plant.

Araceae

#*Alocasia macrorrhiza* (L.) Schott

Koidzumi (1917), Kawagoe (1917), Kanehira (1935), Okabe (1941) all as *A. indica* (L.) Schott.
S 21685; F 26756. Found around villages and in coconut plantations on many islets.
(E) Elephant ear; (M) Majol wot, wot, ot.

(c**Caladium* sp.)

Okabe (1941).

c#*Colocasia esculenta* (L.) Schott

Engler (1897), Schumann and Lauterbach (1901), Volkens (1903), Koidzumi (1917), Okabe (1941) all as *C. antiquorum* Schott.
Seen by Mackenzie. Planted in taro pits on Pinlep Islet.
(E) Taro; (M) Kotak.

c#Cyrtosperma chamissonis (Schott) Merr.

S 21664. After the typhoon seen only in taro pits on Pinlep Islet.
(E) Giant taro; (M) Iarij, iaraj.

c*Rhaphidophora pinnata (L.) Schott

Volkens (1903) as Epipremnum mirabile (L.) Engl.
Seen by Mackenzie and Fosberg. Planted on Jabor.
(E) Tonga plant.

(c * Rhaphidophora sp.)

Okabe (1941).
Possibly the same as the above.

c* Scindapsus aureus (Lindl. and André) Engl.

Okabe (1941) as Scindapsus sp.
Lyman 10. Planted on Jabor.
(E) Taro vine.

c*Xanthosoma sagittifolium (L.) Schott

F 26770. Still growing on Jabor and Pinlep after the typhoon.
(E) Yautia.

Bromeliaceae

(c*Ananas comosus (L.) Merr.)

Engler (1897), Volkens (1903), Koidzumi (1917), Okabe (1941), all as A. sativa L.
(E) Pineapple.

Commelinaceae

(Commelina undulata R. Br.)

Volkens (1903).
It is difficult to say what this plant was.

p*Rhoeo spathacea (Sw.) Stearn

Okabe (1941), Mackenzie, both as R. discolor Hance.
Seen by Fosberg. Growing on Jabor and planted on Imrodj.
(E) Tradescantia.

Liliaceae

(c* _Aloe_ _arborescens_ Mill.)

Okabe (1941).
(E) Aloe.

Agavaceae

c*_Agave_ _sisalana_ Pers.

Koidzumi (1917), Okabe (1941).
Planted on Jabor.
(E) Sisal.

p*_Cordyline_ _fruticosa_ (L.)Goepp.

Okabe (1941).
Lyman 1, _Lyman 2_. Still seen after typhoon on Jabor.
(E) Ti.

p*_Sanseviera_ _guineensis_ (Jacq.) Willd.

Okabe (1941) as _S._ _zeylanica_ and _S._ _zeylanica_ var. _laurentii_.
Lyman 6. Seen on Jabor after typhoon.
(E) Bowstring hemp.

Amaryllidaceae

(c*_Allium_ _fistulosum_ var. _giganteum_ Mak.)

Okabe (1941).
(E) Green onion.

c*_Crinum_ _asiaticum_ L.

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941).
_S 21687_; _F 26749_, _F 26780_. Commonly planted.
(E) Crinum lily; (M) Kiep (Kiebi).

c*_Crinum_ _asiaticum_ var. _procerum_ (Carey) Baker

Seen by Fosberg. Planted around houses.

(c* _Crinum_ _broussonetii_ Herb.)

Okabe (1941).
It is not clear what species Okabe had. This name is said to be a synonym of _C._ _yuccaeflorum_ Salisb. which is not known in the Marshalls.

*Hippeastrum puniceum (Lam.) Urb.

Okabe (1941) as H. hybridum
Seen by Mackenzie and Fosberg. Planted in yards.
(E) Amaryllis.

pc*Hymenocallis littoralis (Jacq.) Salisb.

Schnee 14; F 26762. Planted in yards, apparently established and spontaneous in places.
(E) Spider lily; (M) Kiep.

(c*Pancratium harrisii Hort.)

Okabe (1941).

c*Zephyranthes rosea Lindl.

Okabe (1941) as Z. carinata (Spr.) Herb.
Seen by Fosberg. Planted in yards.
(E) Pink Star-of-Bethlehem

Taccaceae

#Tacca leontopetaloides (L.) O. Ktze.

Volkens (1903), Koidzumi (1917), Okabe (1941), all as T. pinnatifida Forst. f.
S 21693; F 26747. Spontaneous in interior of most larger islets.
(E) Island arrowroot, Polynesian arrowroot; (M) Mok mok.

Dioscoraceae

(c*Dioscorea sp.)

Volkens (1903).
S 21668.
(E) Yam; (M) Mata.

(c* Dioscorea alata L.)

Koidzumi (1917).
(E) Yam.

Musaceae

(c*Musa nana Lour.)

F 26775.
(E) Chinese banana; (M) Jaina kebrang.

c**Musa sapientum* L.

Engler (1897), Volkens (1903), Koidzumi (1917), Okabe (1941).
F 26777. Commonly planted, seen after typhoon.
(E) Banana; (M) Kebran, Majol kebrang (old variety): Abul banana, Emorgargar, Lagatan (varieties introduced by Germans).

Zingiberaceae

(c**Alpinia nutans* (Andr.) Roscoe)

Engler (1897), Volkens (1903), as *A. speciosa* (Wendl.) K. Schum.
(E) Shell ginger.

(c**Curcuma domestica* Val.)

Kawagoe (1917), Okabe (1941) both as *C. longa* L.
(E) Turmeric.

Cannaceae

(c* *Canna indica* L.)

Engler (1897), Schumann, and Lauterbach (1901), Volkens (1903).
(E) Indian shot.

(c**Canna indica* var. *orientalis* Hook. f.)

Okabe (1941).

(c**Canna*, ornamental hybrid)

Lyman 3.

Orchidaceae

(c**Spathoglottis* sp.)

Okabe (1941).
(E) Ground orchid.

(c**Vanda teres* Lindl.)

Okabe (1941).
This probably was Vanda X Miss Joaquim.

Casuarinaceae

Casuarina equisetifolia L.

Okabe (1941).
Lyman 7; F 39469. Planted on Jabor.
(E) Ironwood.

Piperaceae

*Peperomia pellucida Kunth

Koidzumi (1915) as var. obtusifolia, (1917); Yuncker (1938,1959), Okabe (1941).
Koidzumi in 1915 (det. Yuncker); F 39457. Spontaneous on Jabor.

Peperomia ponapensis C. DC.

Volkens (1903) as Peperomia sp.; Yuncker (1959).
F 26734, F 39443. Rare, growing on rocks in forest, found after typhoon on Mejurirek Islet.
(M) Dapidjoka.

Moraceae

Artocarpus altilis (Park.) Fosb.

Schumann & Lauterbach (1901), Volkens (1903) both as A. incisa Forst. /sic/, Koidzumi (1917), Okabe (1941) both as A. communis Forst. f.
S 21696. Seedless form said, by Volkens, to have been introduced from Samoa. Important food plant.
(E) Breadfruit; (M) Mai (me) (Dadarkrak, farlahr, mefawan).

c#Artocarpus mariannensis Trec.

Engler (1897) (probably); Koidzumi (1917) as Artocarpus sp.
F 26758, F 26771. This is the species found wild in the Marianas and widely introduced in other parts of Micronesia, apparently hybridizes with A. altilis.
(E) Wild breadfruit; seedy breadruit.

(c*Ficus carica L.)

Engler (1897), Volkens (1903), Okabe (1941).
(E) Fig.

c*Ficus elastica Roxb.

Okabe (1941).
Seen by Lyman, Mackenzie, and Fosberg. Planted on Jabor.
(E) Rubber tree.

#*Ficus tinctoria* Forst. f.

Okabe (1941).
Seen by Fosberg on Jabor after typhoon.

Urticaceae

(**Boehmeria nivea* (L.) Gaud.)

Volkens (1903)
Judging by the vernacular name give, "aremue", this probably is a misidentification of *Pipturus argenteus*.
(E) Ramie.

Fleurya ruderalis (Forst. f.) Gaud. ex Wedd.

Schumann (1888), Engler (1897), Schumann and Lauterbach (1901), Koidzumi (1917); Okabe (1941) as *F. interrupta* Gaud.
Schnee in 1902; S 21699; F 26716, F 26761. Common generally.
(M) Nenkutikut, neenkotkot (nen gedeget i.e. bird's leg, Volkens).

**Pilea microphylla* Liebm.

Volkens (1903) as *Pilea* sp.; Koidzumi (1915, 1917), Kanehira (1935), Okabe (1941).
S 21670; F 26718. On Jabor, Kinajon, and Pinlep Islets after the typhoon.
(E) Artillery plant; (M) Likotot tot.

Pipturus argenteus (Forst. f.) Wedd.

Schumann and Lauterbach (1901), Volkens (1903), Koidzumi (1915, 1917), Kanehira (1935), Okabe (1941) all as *P. incanus* (Bl.) Wedd.; Kawagoe (1917), as *P. velutinus* Wedd.
S 21692, F 26753. Common on most islets, an abundant pioneer on land devastated by typhoon.
(M) Arme, aremue, armwe.

Procris pedunculata (Forst. f.) Wedd.

F 39442. In wet forest on Majurirek.

Proteaceae

(c**Grevillea robusta* Cunn.)

Volkens (1903).
(E) Silk-oak.

Polygonaceae

(c*Antigonon leptopus H. & A.)

Okabe (1941).
(E) Mexican creeper.

(c*Coccoloba uvifera L.)

Seen by Mackenzie and Fosberg before typhoon.
(E) Sea grape.

Amaranthaceae

(c*Amaranthus blitum var. oleraceus Hook. f.)

Koidzumi (1915, 1917), Kanehira (1935) both as A. blitum L.; Okabe (1941).
(E) Chinese spinach.

*Amaranthus viridis L.

F 39473. Weed on Jabor and Kinajon.

(c* Celosia argentea L.)

S 21669; F 26728. Planted on Imroj before the typhoon.
(E) Cockscomb.

c*Gomphrena globosa L.

Volkens (1903), Koidzumi (1917), Okabe (1941).
Seen by Fosberg on Jabor and Majurirek.
(E) Pearly everlasting.

Nyctaginaceae

Boerhavia diffusa L.

Volkens (1903), Kanehira (1935), Okabe (1941).
These records probably refer to B. tetrandra Forst. or possibly B. repens L.

Boerhavia tetrandra Forst.

F 41418. Very local on Majurirek and Mejatto Islets.
(M) Dapijdoka.

(c* Bougainvillea glabra Choisy)

Seen by Mackenzie.
(E) Bougainvillea.

Bougainvillea spectabilis Willd.

Koidzumi (1917), Okabe (1941).
Seen by Mackenzie and Fosberg.
(E) Bougainvillea.

c*Mirabilis jalapa L.

Volkens (1903) as M. jalappa L.; Koidzumi (1915, 1917), Kanehira (1935), Okabe (1941).
S 21674; F 26754. Planted around dwellings.
(E) Four-o'clock; (M) Emen aur.

Pisonia grandis R. Br.

S 21678; F 26721, F 39482, F 39483. On most islets, important on Ribon and Lijeron.
(M) Kangl.

Portulacaceae

*Portulaca oleracea L.

Volkens (1903), Koidzumi (1915, 1917), Kanehira (1935), Okabe (1941).
F 26708, F 39433. Ruderal on most islets.
(M) Marmilyan.

Annonaceae

(c*Annona cherimola Mill.)

Engler (k897), Volkens (1903), Koidzumi (1917).
(E) Cherimoya.

(c*Annona muricata L.)

Koidzumi (1917), Okabe (1941).
(E) Sour sop.

(c*Annona squamosa L.)

Koidzumi (1917).
(E) Sugar apple, sweetsop.

Lauraceae

Cassytha filiformis L.

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941).
Schnee 34; Betche in 1881; F 26722. Parasite on various plants mostly in open places rather than in shade.

Hernandiaceae

Hernandia sonora L.

Volkens (1903), Koidzumi (1917), Okabe (1941) all as H. peltata Meisn.
F 26778, F 41395. Occasional on most islets.
(M) Bingbing (Bin-e-wing), pingping.

Capparidaceae

(c* Capparis cordifolia Lam.)

Koidzumi (1917) as C. mariana DC.

Cruciferae

(*Brassica acanthiformis Morel)

Okabe (1941).
Seen by Mackenzie.
(E) Giant radish, daikon.

Nasturtium sarmentosum (Forst.) O.E.Sch.

Volkens (1903), Koidzumi (1915, 1917) both as Cardamine hirsuta var. tenuifolia Volk.
Koidzumi in 1915; F 39471. Weed in old botanical garden on Jabor.

Crassulaceae

*Kalanchoe pinnata (Lam.) Pers.

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941) all as Bryophyllum calycinum Salisb.; Kanehira (1935) as Bryophyllum pinnatum (Lam.) Kurz.
S 21665; F 26752. Twenty years earlier (1883) not found on Jaluit (Volkens). Seen on Imroj and Kinajon after typhoon.
(E) Air plant; (M) Jemata.

Rosaceae

(c*Eriobotrya japonica Lindl.)

Volkens (1903).
(E) Loquat.

Leguminosae

(c*<u>Albizia</u> <u>lebbek</u> (L.) Benth.)

Okabe (1941).
Seen by Mackenzie
(E) Woman's tongue tree.

<u>Caesalpinia</u> <u>bonduc</u> (L.) Roxb.

<u>F 41393</u>. Very local on Enybor and Imrodj Islets, probably recently introduced in drift.

(c* <u>Caesalpinia</u> <u>pulcherrima</u> (L.) Sw.)

Volkens (1903), Koidzumi (1917), Okabe (1941).
<u>S 21659</u>; <u>F 26769</u>.
(E) Pride-ofBarbados; (M) Jemata, Emenawa.

(*<u>Canavalia</u> <u>ensiformis</u> (L.) DC.)

Schumann (1888), Schumann and Lauterbach (1901), Volkens (1903), Koidzumi (1915, 1917), Kanehira (1935).
Doubtfully this species, more probably a misidentification of <u>C. microcarpa</u>.
(E) Jack bean; (M) Marlap.

<u>Canavalia</u> <u>microcarpa</u> (DC.) Piper

Okabe (1941).
<u>F 26691</u>, <u>F 39439</u>. Occasional on several islets, climbing in thickets.
(M) Marlap.

*<u>Cassia</u> <u>occidentalis</u> L.

Engler (1897) (brought from Honolulu), Volkens (1903), Koidzumi (1915, 1917), Kanehira (1935), Okabe (1941).
(E) Coffee senna.
Seen by Fosberg.

(*<u>Cassia</u> <u>torosa</u> Cav.)

Okabe (1941).

(c*<u>Clitorea</u> <u>ternatea</u> L.)

Kawagoe (1918).

*<u>Crotalaria</u> <u>incana</u> L.

<u>F 39478</u>. Abundant on bare ground in Jabor after typhoon.
(E) Rattle-pod.

(*Crotalaria longirostrata H. & A.)

Koidzumi (1917); Okabe (1941) as Crotalaria sp.

(*Crotalaria mucronata Desv.)

Okabe (1941) as C. saltiana Andr.
(E) Rattle-pod.

(*Crotalaria speciosa Heyne ex Roth)

Volkens (1903).

c*Delonix regia (Bojer) Raf.

Okabe (1941).
Seen by Mackenzie and Fosberg. Tree in botanical garden survived typhoon but in poor condition.
(E) Royal poinciana.

Entada pursaetha DC.

F 41411. Seedling from germinated drift seed.
(E) Snuff box bean.

c*Erythrina variegata var. orientalis (L.) Merr.

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941) all as E. indica Lam.
Seen by Fosberg. Survived typhoon in botanical garden.
(E) Coral tree.

c*Inocarpus fagiferus (Park.) Fosb.

Volkens (1903), Koidzumi (1917), Okabe (1941) all as I. edulis Forst.
Seen by Mackenzie, and Fosberg. Tree in botanical garden survived typhoon.
(E) Tahitian chestnut.

Intsia bijuga (Colebr.) O. Ktze.

Okabe (1941).
F 26774, F 39437, F 39480. Occasional on several islets.
(M) Kubok, Kubuk, kubuik.

p*Leucaena leucocephala (Lam.) deWit

Okabe (1941).
Lyman 8; Seen by Fosberg after typhoon on Jabor.

(c* Phaseolus lunatus L.)

Koidzumi (1917), Okabe (1941).
(E) Lima bean.

(c*Pithecellobium dulce (Roxb.) Benth.)

Okabe (1941).

(c*Samanea saman (Jacq.) Merr.)

Volkens (1903) as Pithecellobium saman (Jacq.) Benth.
(E) Monkey pod, rain tree.

(*Sesbania grandiflora (L.) Pers.)

Okabe (1941).

Sophora tomentosa L.

Okabe (1941).
F 26783. Rare, seen by Fosberg on Enybor Islet.
(M) Kil'li, kille.

Vigna marina (Burm.) Merr.

Volkens (1903), Kawagoe (1917), Okabe (1941) all as V. lutea (Sw.) Gray
S 21688; F 26739, F 41412. Common on beaches and in partial shade.
(E) Beach pea; (M) Margnanjojo, Markunenjojo.

Rutaceae

c*Citrus aurantifolia (Christm.) Swingle

Volkens (1903) as C. limonum L.; Okabe (1941) as Citrus sp.
Seen by Mackenzie and Fosberg. Planted around dwellings.

(c*Citrus paradisi Macf.)

Seen by Mackenzie.
(E) Grapefruit.

(c*Citrus reticulata Blanco)

Seen by Mackenzie.
(E) Tangerine.

c*Citrus sinensis (L.) Osb.

Seen by Mackenzie both before and after typhoon.
(E) Sweet orange.

Surianaceae

Suriana maritima L.

Volkens (1903), Kanehira (1935).
Not found recently, but in all probability present somewhere on the atoll, as it is a very common and widespread atoll species.

Burseraceae

(*Canarium commune L.)

Okabe (1941).
(E) Canari nut.

Meliaceae

(c* Melia azederach L.)

Volkens (1903), Koidzumi (1917), Okabe (1941).
(E) Pride of India.

Euphorbiaceae

c*Acalypha wilkesiana Muell. -Arg.

Seen by Mackenzie and Fosberg. Planted around dwellings.
(E) Joseph's coat; beefsteak plant.

c* Codiaeum variegatum (L.) Bl.

Volkens (1903), Okabe (1941).
Schnee in 1902. Planted around houses in Majurirek.
(E) Croton.

(c*Euphorbia bojeri Hook.)

Volkens (1903), Koidzumi (1917) both as E. splendens Boj.
Schnee 23.
(E) Crown of thorns.

Euphorbia chamissonis (Kl. & Gke.) Boiss.

Koidzumi (1917) as E. sparmannii; Kawagoe (1918), Okabe (1941) both as E. atoto Forst. f.
Koidzumi in 1915; F 26686, F 26698, F 39438. Common in plantations, surviving after typhoon on leeward islets.
(E) Beach spurge; (M) Berau, Perau.

(*Euphorbia cyathophora Murr.)

Koidzumi (1917), Kawagoe (1918), Okabe (1941) all as E. heterophylla L.
(E) Dwarf poinsettia.

*Euphorbia glomerifera (Millsp.) Wheeler

F 41402a. Weed on Jabor, rare.

*Euphorbia hirta L.

Volkens (1903), Koidzumi (1917), Okabe (1941) all as E. pilulifera L.
F 26717. Ruderal on several islets.
(E) Hairy spurge.

(c*Euphorbia neriifolia L.)

Okabe (1941).

*Euphorbia prostrata L.

Kawagoe (1918).
Schnee 27 (or 124); F 26714, F 39463, F 41402. Ruderal around villages.

(c*Euphorbia pulcherrima Willd.)

Okabe (1941).
Seen by Mackenzie.
(E) Poinsettia

*Euphorbia thymifolia L.

Koidzumi (1915, 1917), Okabe (1941).
F 39470, F 41399. Ruderal around villages.

(c*Euphorbia trigona Haw.?)

Kawagoe (1918).

(*Jatropha sp.)

Okabe (1941).

(c*Macaranga tanarius (L.) M.-A.)

Koidzumi (1915, 1917).
This record and the following do not sound likely but it is not clear what the plants may have been.

(c*Macaranga tanarius var. glabra Muell.-Arg.)

Schumann & Lauterbach (1901), Volkens (1903).

(c*Manihot esculenta Crantz)

Okabe (1941) as M. utilissima Pohl
(E) Tapica, Cassava.

*Phyllanthus amarus Schum. & Thonn.

Koidzumi (1917), Kanehira (1935), Okabe (1941) all as P. niuri L. /sic./
F 26719, F 41394. Weed, especially in cleared ground.

(*Ricinus communis L.)

Engler (1897), Volkens (1903).
Seen by Mackenzie
(E) Castor oil bean.

Anacardiaceae

(c*Mangifera indica L.)

Koidzumi (1917), Okabe (1941)
(E) Mango.

Sapindaceae

Allophylus timorensis Bl.

Schumann (1888); Engler (1897) as A. cobbe (L.). Bl; Schumann & Lauterbach (1901), Volkens (1903), the latter both as A. timorensis and Allophilus cobbe (L.) Bl.; Koidzumi (1915, 1917), Radlkofer (1932), Okabe (1941); Kawagoe (1918),as A. cobbe f. racemosus (L.) Engl. and A. cobbe f. rheedii (Wight) Engl.; Radlkofer (1932) also as A. ternatus (Forst.) Radlk.
S 21689; F 26688, F 26692a, F 26773, F 41410. Common, generally, in thichets and forest.
(M) Ketak, kutak, kudan

(*Pometia pinnata Forst.)

Volkens (1903).

Tiliaceae

Triumfetta procumbens Forst. f.

Schumann (1888), Schumann and Lauterbach (1901), Volkens (1903), Koidzumi (1915, 1917), Kawagoe (1918), Okabe (1941).
Schnee 41; S 21694; F 26700, F 26743. Common generally.

Malvaceae

(c*<u>Gossypium</u> <u>peruvianum</u> Cav.)

Okabe (1941) as <u>G</u>. <u>brasiliense</u> Macf.
(E) Cotton.

c*<u>Hibiscus</u> <u>esculentus</u> L.

Okabe (1941) as <u>Abelmoschus</u> <u>esculentus</u> (L.) Moench.
Seen by Mackenzie and Fosberg. Planted on Jabor.
(E) Okra.

(c*<u>Hibiscus</u> <u>mutabilis</u> L.)

Seen by Mackenzie.
(E) Variable rose

(c*<u>Hibiscus</u> <u>rosa-sinensis</u> L.)

Volkens (1903), Koidzumi (1917), Okabe (1941).
<u>Schnee</u> in 1902
(E) Hibiscus.

#<u>Hibiscus</u> <u>tiliaceus</u> L.

Volkens (1903), Koidzumi (1915, 1917), Kawagoe (1917), Okabe (1941).
<u>Schnee</u> in 1902; <u>S 21686</u>; <u>F 26720</u>, <u>F 41379</u>, <u>F 41403</u>.
(M) Law (loa, roh).

c*<u>Hibiscus</u> (ornamental hybrid)

Seen by Fosberg.

(*<u>Malvastrum</u> <u>coromandelianum</u> (L.) Garcke)

Volkens (1903).

(<u>Sida</u> <u>fallax</u> Walp.)

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941); Kawagoe (1918), as <u>S</u>. <u>cordifolia</u> L.
<u>Schnee</u> in 1902; <u>F 26776</u>.
(M) Kio

(*<u>Sida</u> <u>rhombifolia</u> L.)

Volkens (1903).

(*<u>Thespesia</u> <u>populnea</u> (L.) Sol. ex Correa)

Seen by Mackenzie.

Bombacaceae

(c*Bombax ellipticum HBK.)

Seen by Mackenzie

c*Ceiba pentandra (L.) Gaertn.

F 26760. Planted on Jabor.
(M) Bulik.

Guttiferae

#Calophyllum inophyllum L.

Engler (1897), Volkens (1903), Koidzumi (1915, 1917), Okabe (1941).
S 21699; F 26725, F 26788. On most islets.
(M) Lues, ligwait, rukehah, lukwej, luej.

Caricaceae

c*Carica papaya L.

Engler (1897), Volkens (1903), Koidzumi (1917), Okabe (1941).
Planted on most islets.
(M) Kinabu, Kehnap.

Passifloraceae

(c*Passiflora edulis Sims)

Kawagoe (1918).
(E) Passion fruit.

(c*Passiflora foetida L.)

(Kawagoe (1918).

(c*Passiflora laurifolia L.)

Seen by Mackenzie.

Cucurbitaceae

(c*Citrullus vulgaris Schrad.)

Seen by Mackenzie.
(E) Water melon.

(c*Cucumis melo var. conomon Makino)

Okabe (1941).

(c*Cucumis sativus L.)

Okabe (1941).
Seen by Mackenzie and Fosberg. Planted on Imrodj Islet.
(E) Cucumber.

c*Cucurbita moschata var. toonas Makino

Koidzumi (1917) as C. mexicana Duch.; Okabe (1941).
Possibly still grown, but not identified with certainty since the typhoon.
(E) Squash.

c*Curcurbita pepo L.

Seen by St. John; F 26703 possibly goes here. Cucurbits are still commonly planted, but what species is not positively known.

Lythraceae

Pemphis acidula Forst.

Schumann (1888), Schumann & Lauterbach (1901), Volkens (1903), Koidzumi (1915, 1917) Kawagoe (1918), Okabe (1941).
F 26711. Common on rocky, very saline areas.
(M) Kengi (könge)

Punicaceae

(c*Punica granatum L.)

Engler (1897), Volkens (1903).
(E) Pomegranate.

Sonneratiaceae

Sonneratia alba J. Sm.

F 26690, F 41391. Collected south of Jabor in 1946, gone from there after typhoon, but still common in swamp on Jaluit Islet.
(M) Pulabl, kinpat.

Rhizophoraceae

Bruguiera gymnorhiza (L.) Lam.

Schumann (1888) as B. rheedii Bl.; Engler (1897) as Bruguiera sp., Volkens (1903), Koidzumi (1915, 1917); Okabe (1941) as B. conjugata (L.) Merr.
F 26738. Abundant in swamps on most islets.
(M) Jong (djong) (Shon). (E) Mangrove.

(Rhizophora mucronata Lam.)

Koidzumi (1917).
(E) Mangrove.

Combretaceae

Lumnitzera littorea (Jack) Voigt

F 26742, F 41390. In mangrove depressions.
(M) Kimum, kimeme.

(c*Quisqualis indica L.)

Volkens (1903).

#Terminalia catappa L.

Engler (1897), Schumann & Lauterbach (1901), Volkens (1903), Koidzumi (1915, 1917), Okabe (1941).
F 26763. Planted around villages.
(M) Kotal, kutil.

Terminalia samoensis Rech.

Koidzumi (1915) as T. litoralis Seem.; Kawagoe (1918), as Terminalia sp.; Okabe (1941) as T. saffordii Merr.
S 21684; F 26723, F 39436. Found on several islets, especially leeward ones.
(M) Kung, Ekung, ekkin, kikin.

Lecythidaceae

Barringtonia asiatica (L.) Kurz

Engler (1897), Schumann & Lauterbach (1901), Volkens (1903), Kawagoe (1918), all as B. speciosa Forst.; Koidzumi (1915, 1917), Knuth (1939).
S 21667; F 26736. Uncommon, survived typhoon at least on Imroj and Mejat'to.
(M) Wop (oup).

(c*Couroupita guianensis Aubl.)

Okabe (1941).
(E) Cannonball tree.

Melastomaceae

(*Miconia sp.)

Seen by Mackenzie. A very unlikely record.

Cactaceae

(c*Cereus sp.)

Okabe (1941).

(c*Epiphyllum oxypetalum Haw.)

Okabe (1941).

(c*Opuntia sp.)

Kawagoe (1918), Okabe (1941).

Onagraceae

#Jussiaea suffruticosa L.

F 41406. Found in taro pits on Pinlep Islet.

Araliaceae

c*Brassaia actinophylla Endl.

Kawagoe (1918), Okabe (1941) as Schefflera sp.
Seen by Mackenzie and Fosberg. Planted on Jabor; has strangeler habit.
(E) Octopus tree.

(c*Polyscias filicifolia (S. Moore) Bailey)

Okabe (1941) as Aralia filicifolia Chr. A plant reported by Kawagoe (1918) as Nothopanax sp. may belong here.
Lyman 5.
(E) Panax.

(c*Polyscias fruticosa (L.) Harms)

Kawagoe (1918).
F 26787. Seen by Mackenzie.
(E) Panax.

(c*Polyscias guilfoylei (Cogn. & March.) Bailey)

Koidzumi (1917) as Aralia guilfoylei Cogn. & March; Kawagoe (1918) as Nothopanax guilfoylei (Cogn. & March.) Merr.
Lyman 9; S 21656.
(E) Hedge panax.

c*Polyscias scutellaria (Burm. f.) Fosb.

Koidzumi (1917) as Nothopanax cochleata Miq.; Okabe (1941) as Nothopanax scutellaria Merr.
S 21656; F 26786. Survives on Majurirek, planted in village.
(E) Panax.

c*Polyscias tricochleata (Miq.) Fosb.

Okabe (1941) as Nothopanax tricochleatum Miq.
F 26781. Planted on Pinlep.
(E) Panax.

Umbelliferae

Centella asiatica (L.) Urb.

Okabe (1941).
F 26731, F 39434. Ruderal onseveral islets.
(M) Maruko, madiko.

(c* Oenanthe stolonifera DC.)

Okabe (1941).

Oleaceae

c*Jasminum sambac (L.) Ait.

Seen by Fosberg. Planted on Kinajon Islet.
(E) Jasmine.

Apocynaceae

*Catharanthus roseus (L.) G. Don

Schnee 29. Growing in cemetery on Pinlep, after typhoon.
(E) Periwinkle.

c*Cerbera manghas L.

Volkens (1903), Koidzumi (1915, 1917) both as C. lactaria Ham.; Okabe (1941).
Seen by Mackenzie, Fosberg. Planted on Jabor.
(M) Kitjebar, Kejbar.

c*Nerium indicum Mill.

Okabe (1941) as N. odorum Sol.
F 26785. Planted in villages.
(E) Oleander.

c*Nerium oleander L.

Volkens (1903), Koidzumi (1917).
F 26730. Planted in villages.
(E) Oleander.

Ochrosia oppositifolia (Lam.) Schum.

Okabe (1941) as O. parviflora (Forst.) Hensl.
F 26735. Survives on northwest end of Imroj Islet.
(M) Kijbar, kejbar.

c*Plumeria rubra L.

Okabe (1941) as P. acutifolia Poir.
S 21671; F 26726. Planted in villages.
(E) Frangipani; (M) Meria.

(c*Vinca major L.)

Volkens (1903).
May have been a misidentification of Catharanthus roseus.
(E) Periwinkle.

Asclepiadaceae

*Asclepias curassavica L.

Volkens (1903).
F 26727. Seen after typhoon in cemetery on Pinlep Islet, also planted on Imrodj.
(E) Milkweed.

Convolvulaceae

c* Ipomoea batatas (L.) Poir.

Engler (1897) introduced from Kusaie; Volkens (1903).
F 26748. Planted on Mejatto Islet.
(E) Sweet potato.

Ipomoea littoralis Bl.

Engler (1897), Schumann & Lauterbach (1901), Okabe (1941) all as I. denticulata Choisy.
Schnee in 1902, Schnee 8; S 21683; F 26765, F 39455. Persists at least on Jabor and Pinlep Islets.
(M) Lodjeringin Kidjerik.

Ipomoea pes-caprae ssp. brasiliensis (L.) Van Ooststr.

Engler (1897), Schumann & Lauterbach (1901), Volkens (1903), Koidzumi (1915, 1917), Okabe (1941) all as I. pes-caprae (L.) Roth
Koidzumi in 1915; F 26709. Persists on Jabor; seedling from beach drift on Ribon Islet.
(E) Beach morning-glory; (M) Markinenjojo.

Ipomoea tuba (Schlecht.) Don

Engler (1897) as Calonyction speciosum Choisy; Schumann & Lauterbach (1901), Volkens (1903) both as Calonyction bona-nox (L.) Boj.; Kawagoe (1917) as Ipomoea sp.; Koidzumi (1915, 1917), Kanehira (1935) both as I. grandiflora Lam.; Okabe (1941) as Calonyction album (L.) House.
Koidzumi in 1915; S 21680; F 26685, F 39460. On several islets.
(E) Moonflower; (M) Marlap, Marbelle, marpele.

Boraginaceae

Cordia subcordata Lam.

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941).
F 26696, F 26724, F 39421. On most islets, especially at top of lagoon beach.
(M) Kӧno.

Tournefortia argentea L.f.

Schumann (1888), Schumann & Lauterbach (1901), Volkens (1903), Koidzumi (1915, 1917); Okabe (1941) as Messerschmidia argentea (L.) Johnst.
F 26699. Found generally. A widespread atoll species.
(M) Kirin.

Verbenaceae

Clerodendrum inerme (L.) Gaertn.

Volkens (1903) as Clerodendron sp.; Okabe (1941) as Clerodendron inerme Gaertn.
Schnee in 1902; F 26733. Said by Volkens to have been introduced from Ponape [but occurs generally in Marshalls].
(M) Uleg, Uledj, wuledj.

(c*Lantana camara var. aculeata (L.) Mold.)

Engler (1897), Volkens (1903) both as L. aculeata L.; Okabe (1941) as L. camara L.
Seen by Mackenzie.
(E) Lantana.

Premna obtusifolia R. Br.

Kawagoe (1917) as Premna sp.; Okabe (1941) as P. gaudichaudii Schauer
F 26732, F 26789. Occasional in thickets on most islets.
(M) Kaar

*Stachytarpheta urticifolia Sims

Koidzumi (1917), Okabe (1941) both as S. dichotoma Vahl.
F 39476, F 41383. Occasional on Jabor.

Labiatae

(c*Coleus scutellarioides L.)

Okabe (1941) as C. blumei Benth.
(E) Coleus.

(c*Ocimum basilicum L.)

Okabe (1941).
This report is possibly based on O. sanctum L., though O. basilicum is occasionally planted in gardens in other atolls and could possibly have been here.
(E) Basil.

#Ocimum sanctum L.

Volkens (1903).
S 21658; F 26755. Said by Volkens to have been introduced by missionaries. Commonly planted around dwellings.
(M) Katrin.

(c*Plectranthus graveolens R. Br.)

Volkens (1903).

Solanaceae

(c*Capsicum annuum L.)

Engler (1897), Schumann & Lauterbach (1901), Volkens (1903).
(E) Chili, red pepper.

(c*Capsicum longum L.)

Volkens (1903).
Possibly refers to a form of C. frutescens L.

(*Nicotiana tabacum L.)

S 21672; F 26707.

*Physalis angulata L.

Volkens (1903) as P. minima L.; Koidzumi (1915, 1917), Kanehira (1935), Okabe (1941).
F 26710. Ruderal on several islets.

(c*Solanum lycopersicum L.)

Okabe (1941) as Lycopersicum esculentum Mill.
(E) Tomato.

#Solanum nigrum L.

Engler (1897), Schumann & Lauterbach (1901) both as S. oleraceum Dunal; Volkens (1903) as S. nigrum L. and S. oleraceum Dunal; Koidzumi (1915, 1917) as S. oleraceum Dunal.
F 39475. Persisting at least on Jabor and Pinlep Islets, ruderal.
(E) Nightshade.

Scrophulariaceae

c*Angelonia angustifolia Benth.

Seen by Fosberg, planted on Imroj.

Bignoniaceae

(c*Jacaranda filicifolia Benth.)

Seen by Mackenzie.
(E) Jacaranda.

Acanthaceae

(c*Barleria cristata L.)

Okabe (1941).

(c*Beloperone guttata Brandeg.)

Seen by Mackenzie.
(E) Shrimp plant.

*Blechum brownei f. puberulum Leonard

Okabe (1941) as B. pyramidatum (Lam.) Urb.
F 39472. Growing on Jabor.

*Hemigraphis reptans (Forst.) Engler

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941).
F 39461, F 41384. Ruderal on Jabor and Pinlep; uncommon.

pc*Pseuderanthemum carruthersii (Seem.) Guill. var. carruthersii

Okabe (1941) as Eranthemum eldorado.
F 26782, F 39423. Planted and persisting around dwellings and former dwelling sites.
(M) Ulej.

pc*Pseuderanthemum carruthersii var. atropurpureum (Bull) Fosb.

Lindau (1915) as P. jaluitense Lindau; Okabe (1941) as Eranthemum atropurpureum Bull.
F 26729, F 39424.
(M) Ulej.

(*Ruellia sp.)

Volkens (1903).

Rubiaceae

*Dentella repens Forst.

F 39458, F 41397. Ruderal on Jabor.

Guettarda speciosa L.

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941).
F 26692. General on most islets, one of the most widely distributed atoll plants.
(M) Wot, Wüott, utt.

#Hedyotis biflora (L.) Lam.

Okabe (1941) as Oldenlandia sp.
S 21660; F 26768, F 26784. Ruderalon several islets.
(M) Glarkio.

Hedyotis corymbosa (L.) Lam.

F 41398.

(#Ixora casei Hance)

Volkens (1903), Okabe (1941) both as Ixora sp.
Schnee in 1902; S 21666.
(M) Kajiru. (E) Ixora.

(*Ixora fraseri Hort. ex Gentil)

Seen by Mackenzie.

#Morinda citrifolia L.

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941).
Schnee in 1901, Schnee in 1902; S 21690; F 26687. In the interior of most islets.
(M) Nin, Nen.

(#Randia cochinchinensis (Lour.) Merr.)

Okabe (1941) as R. racemosa F. Vill.

Caprifoliaceae

(c*Sambucus mexicana var. bipinnata (S. & C.) Schwerin?)

Okabe (1941) as Sambucus sp.

Campanulaceae

*Hippobroma longiflora (L.) Don

Seen by Fosberg on Jabor in 1958.

Goodeniaceae

Scaevola taccada (Gaertn.) Roxb.

Engler (1897), Schumann & Lauterbach (1901), Volkens (1903) all as S. Koenigii Vahl; Krause (1912), Koidzumi (1915, 1917) Okabe (1941) all as S. frutecens (Mill.) Kr.; Fosberg (1961) as S. sericea Vahl.
S 21691; F 26702. Abundant at tops of beaches, especially seaward beaches, and less so in interiors of islets; one of the commonest of atoll plants.
(M) Kunnat, Kenat.

Compositae

#Adenostemma lavenia (L.) O. Ktze.

S 21661; F 26767. In interior of Kinajon Islet, formerly on Imroj.

*Ageratum conyzoides L.

Volkens (1903), Koidzumi (1915, 1917), Kanehira (1935), Okabe (1941).
F 39485. Said by Volkens to have been introduced from Ponape.
Ruderal, on Jabor.

(c*Cichorium endivium L.)

Seen by Mackenzie.
(E) Endive.

(c*Coreopsis basalis (Dietr.) Blake)

Okabe (1941) as C. drummondii T. & G.
(E) Coreopsis.

(*Spilanthes iabadicensis A. H. Moore)

Seen by Mackenzie.

*Synedrella nodiflora (L.) Gaertn.

Volkens (1903), Koidzumi (1915, 1917), Okabe (1941).
F 39477. Ruderal on several islets.

c*Tagetes sp.

Seen by Fosberg, planted on Majurirek Islet.
(E) Marigold.

*Vernonia cinerea (L.) Less.

Volkens (1903), Koidzumi (1915, 1917), Kanehira (1935), Okabe (1941).
S 21700; F 26750, F 39484. Ruderal, on several islets.

Wedelia biflora (L.) DC.

Schumann & Lauterbach (1901), Volkens (1903), Koidzumi (1915).
Kawagoe (1917), Kanehira (1935), Okabe (1941).
S 21675; F 26693. Very common, abundant in open places.
(M) Markuwewe, markebuebue, moredjit, merguebit.

c*Zinnia elegans Jacq.

Seen by Fosberg, planted around dwellings on Jabor.
(E) Zinnia.

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A brief survey of the cays of Arrecife Alacran, a Mexican atoll

by

F. R. Fosberg

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A brief survey of the cays of Arrecife Alacran,

a Mexican atoll

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It has long seemed desirable to make comparisons of atolls, atoll-like reefs, and islands between the three different oceans where such phenomena occur. A talk by J. T. Conover, Jr. before an AAAS Section G audience in 1960 on his investigations on Arrecife Alacran, Yucatan, indicated some features of the reefs that seemed vastly different from any I had observed on the Pacific Atolls. On his invitation I made a short visit to Alacran during his second visit there, in July 1961. This trip was made possible by a grant of funds from the Office of Naval Research through the Pacific Science Board. Eight days were spent on the Reef, during which it was possible to visit all six of the cays.

My sincere thanks are extended to Mr. Charles Hoskin and Dr. Conover, in charge, respectively, of the University of Texas and the University of Rhode Island-Duke University parties that were working on Alacran (and to Sr. Cabanas, lighthouse keeper on Alacran), for their kind hospitality and invaluable assistance in enabling me to visit the cays, as well as for freely sharing their knowledge of the Reef, making it possible to develop some familiarity with it, in spite of the shortness of the time I spent there. I can only hope that our discussions were as stimulating to them as they were to me. A brief notice of their investigations, as well as those of Professor F. Bonet, and his associates, may be found in Atoll Research Bulletin 84.

Until recently, Alacran was one of the least known of atolls, although it was described as early as 1699 by William Dampier, the English privateer-writer, in whose work is found some of the earliest carefully recorded field natural history. Descriptions were again made by Alexander Agassiz in 1888, and by C. F. Millspaugh, in 1916. During the last few years much investigation has been accomplished (see ARB 84), but rather little of it has been published as yet. In terms, at least, of observations in manuscript, Alacran has now become one of the best known of atolls. It has even joined the select company of atolls that have been investigated in depth by core drilling.

Arrecife Alacran has been described and a small-scale map of it published by Kornicker and associates (1959), and some of the fauna listed from their collections made in 1959. Also a detailed study of the reefs and especially of the roles of the various reef organisms has just been published by Kornicker and Boyd (1962). The emphasis of both these papers is mainly on the reefs and the marine aspects. The map shows Alacran as an intricate network of reefs, roughly oval in shape, with an arcuate, practically uninterrupted windward reef. Accumulated boulders on this break the water surface at low tide. The cays or islets are on the leeward side, mostly toward the north and south ends of this reef, and together they do not aggregate more than 0.5 sq. km in area.

The largest cay is Perez, with the lighthouse and weather station. Southeast of this are Pajaros and Chica, near the south end of the reef. About a third of the way up the west side is Desertora (Allison Cay) and at the north end the Desterrada (Utowana) cays, until recently one islet which a storm cut in two by removing the middle part, leaving the two ends separate.

Physiography

The cays are all very low, probably nowhere more than between 3 and 4 m, mostly much lower than this. On each cay, dune ridges and beach ridges account for all land above a general level between 1 and 2 m. No boulder ridges were seen, nor any gravel above pebble-gravel size, except for the piles of _Strombus_ shells mentioned below. A very few scattered boulders, 50 cm or more in largest dimension occur. These are mostly compact, fine-grained limestone, but one or two are pegmatite. In all probability these were brought to Alacran as ballast. Large brain corals are abundant on the reefs, but surprisingly few are thrown up on land, where actually none of any large size were seen. A special search was made for beach rock and emerged reef conglomerate but no consolidated rock of any sort was seen, and it is thought that none exists on any of the cays. Loose lime-sand and "finger gravel" of broken _Acropora cervicornis_ are the most common materials. The sand, in places where birds are especially abundant, is of a dark yellowish brown color, elsewhere white to pale gray-brown. Most of it would correspond either to the Shioya Soil Series of the Pacific islands or to what has been termed Unaltered Sand and Gravel in the Marshall Islands (Fosberg 1959).

The following profile was encountered in a pit, dug for the purpose on Perez Islet just north of the lighthouse buildings, about 90 paces from the seaward beach, 68 paces from the lagoon beach, on ground very gently sloping from a dune ridge toward the lagoon, in a small opening in open _Suriana_ scrub, thickly populated by sooty terns:

0-2 cm: loose dry sand mixed with _Suriana_ litter.
2-3 cm: somewhat caked sand.
3-10 cm: fine sand, thinly and irregularly bedded light and dark gray-brown.
10-35 cm: medium-fine sand, irregularly mottled pale brown and yellow brown, first traces of moisture visible at about 25 cm, _Suriana_ roots common in this layer; they are up to 1 cm thick.
35-65 cm: coarser pale sand with fine roots scattered through it.
65-105 cm: coarse sharp very pale sand.
105-140 cm : coarse sharp white sand with scattered, rather rotten coral fragments.
Water level, at 12:10 p.m., 133 cm, at 3:30 p.m., 133 cm, at 6:00 p.m., 150 cm.

The water in this pit tasted quite salty. A sample, analyzed by S. Rettig, of the U. S. Geological Survey, showed Cl 15,500 ppm., NO_2 1,420 ppm., P as PO_4, 1.2 ppm., HCO_3 437 ppm., pH 7.1, and specific conductance at 25°C 41,700 micromhos. The high nitrate content is doubtless from the excrement of sea birds.

Along the beaches on several of the cays, especially Perez, Chica and Pajaros, are conspicuous ridges or hillocks as much as 1 or 1.5 m high of the large shells of _Strombus gigas._ These shells are thrown there

by fishermen after they have removed the animals to use as bait. Each shell has a hole broken in the smaller whorls. Another curious feature is the frequent occurrence of what appear to be leafless skeletons of a somewhat thorny irregularly branched shrub with a woody enlargement at the base. These are washed-up skeletons of large gorgonians commonly called sea-whips that are very common on the reefs. Purple sea-fans, also common in the beach sediments, are likewise abundant components of the reef community.

Climate

Records kept by the Mexican government weather station on Alacran between January 1959 and the time of my visit, were made available through the courtesy of the personnel of the station, to whom I am very grateful; these show several interesting features, though the period covered is far too short for adequate generalization. Time was only available to study and copy certain features of these records, so wind direction and rainfall distribution were chosen as having the most influence on other features studied, namely physiography and vegetation. Data on wind strength have been compiled from the same set of records by J. T. Conover, and kindly made available to me.

The records of wind direction that are generalized in the accompanying graphs were made three times daily.* The bars on the graphs simply represent the total number of observations of wind from each direction, the bottom bar indicating observations recorded as calm. It is clear that there is a prevailing wind from the east, commonly ranging to northeast or southeast, rarely to north or even northwest. The only months that were notable exceptions, during the $2\frac{1}{2}$ years of record, were November 1959, when the preponderant direction was north with only a moderate easterly component, and September 1960, when the winds were fairly well distributed as to direction. From April through August, the southerly to westerly components are negligible and during the rest of the year almost so. The data assembled by Conover (unpublished) indicate that wind exceeds 20 knots on half or more of the days in 8 months of the year.

The rainfall regime indicated by the station records is so remarkable that it seems necessary to present the actual figures,* generalized only to the extent of adding together the amounts shown by three daily observations into daily totals. The three enormously high figures, 999 mm on each day, on Sept. 11, 1959, Dec. 26, 1960, and Jan. 9, 1961, each represent single readings of the gauge (1 meter), thus being the record for 12 hours or less. It was said that on each of these occasions the gauge overflowed in a storm, so the record should be more than a meter for each of these readings. As the regime indicated by these records is so unusual that it may possibly not be accepted by climatologists, it will not be discussed here, other than to say that the sparseness of the vegetation, its poverty in species, and the extremely xeromorphic character of the plants seem generally consistent with extreme drought.

In the soil pit dug on Perez Islet, the first traces of moisture were encountered at about 25 cm, the sand became wet at 105 cm, and the water was salty. According to the record there had been no rain for 20 days, then only 3 mm, and before that none for 105 days.

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* Graphs and rainfall figures will be found at end of Bulletin.

Vegetation

The vegetation of Alacran has been described in some detail by Bonet and Rzedowski (in press), whose observations agree in most respects with mine. Therefore only a summary need be given here. The vegetation is all of an extremely pioneer character, is composed of few species and shows a strong tendency to form recognizable communities, as well as a tendency toward almost pure stands of single species. Nowhere is the dynamic nature of vegetation better shown. While on the basis of such a brief survey a detailed successional pattern could not be worked out, certain dynamic relationships may be indicated.

Early records of the vegetation of Alacran are meager, indeed. William Dampier, who visited the atoll in 1675, says in the account of his voyage (1931 ed., p. 143) "The Alacranes are 5 or 6 low sandy Islands... On some there are a few low bushes of Burton-wood, but they are mostly barren and sandy, bearing nothing but only a little Chicken-weed; neither have they any fresh water."

Doubtless by "Burton-wood"he means Conocarpus (button wood), now almost lacking on Alacran. What "Chicken-weed" might be is not so clear, though possibly it may be Portulaca oleracea.

T. Smith (1838, pp. 804-805) is perhaps the next to mention the vegetation of Alacran. He says that "these sand bores soon get covered with grass, samphire, and various kinds of herbs." The grass was doubtless Sporobolus virginicus and the samphire must have been Sesuvium. The lack of any mention of shrubs suggests that between Dampier's visit in 1675, and 1838 the atoll may have been swept by a storm of unusual violence and the vegetation removed. However, the West India Pilot (p. 371) says that the three cays at the southeast extreme of the reef were "clothed with grass and brushwood." This is most likely based on a report by T. Smith or by Captain Barnett who surveyed Alacran in the 1840's. Marion (1884) says that in 1865, on Perez there was not a tree, only short grass and sea-fennel (fenouil marin) and one hut.

In 1899 C. F. Millspaugh visited Alacran on the Utowana Expedition and prepared a detailed description and maps of the vegetation of most islets (Millspaugh 1916). The islets were principally covered by Sesuvium, with considerable areas of Sporobolus, and a scattering of other herbs and shrubs.

Since Millspaugh's visit profound changes have occurred. It was evident to Millspaugh that the vegetation of the cays was all of an early pioneer character and he regarded most of it as no more than 57 years old, as, according to him, Pajaros and Chica had been described in 1842 as "bare sand spits devoid of vegetation" and Perez and Allison (Desertora) as having "grass and samphire only." Although he nowhere says so in so many words, Millspaugh apparently regarded the youthfulness of the vegetation as indicating that the islets, themselves, were very young, as he said "The discovery, on these islets, of three species new to science, with the proof that they have evolved within the known and definite period of 57 years, is a fact impressive as it is important." The species

he referred to were Cakile alacranensis Millsp.(apparently a form of C. lanceolata, though the taxonomy of Cakile still leaves much to be desired), Tribulus alacranensis Millsp. (a form of the variable T. cistoides) and Cenchrus insularis Scribn. (C. pilosus H.B.K.). All of these seem to be merely forms or synonyms of more widely distributed, previously described species.

There is, of course, no way of proving that the islets of Alacran either are or are not of such recent origin. It does seem probable that in 1838 and 1842 there was little vegetation. Whether this was a primitive condition is questionable in view of the statements of Dampier and Smith (1838), and since the violence of storms in the region is such that complete denudation of the islets is easily possible and may have taken place not long before the visit of the British survey party in the 1840's. In any event, the report of nothing but grass (Sporobolus) and samphire (Sesuvium) on Perez and Desertora and nothing at all on Pajaros and Chica in 1842 provides an important reference point for estimating the rate of colonization of bare sand cays by plants and of the development of their vegetation.

The possibility that between 1675 and 1838 the woody vegetation may have been entirely destroyed by sealers who would have used it for firewood in trying out seal oil cannot be ignored. However, constant use of Suriana for firewood by the inhabitants of Perez Islet since the lighthouse was established over 40 years ago has not prevented this shrub from becoming the dominant vegetation on the islet. Also, on the similar Pedro Cays, south of Jamaica, annual clearing of woody vegetation to facilitate egg gathering, has not, in many years, eliminated this vegetation. The woody plants concerned sprout readily from the root crowns, and these crowns are not easily pulled out by such ordinary means as would likely be employed by firewood gatherers.

The discernible plant communities or vegetation types are listed below and briefly characterized; their relations with substratum variations, something of their patterns of arrangement, and historical changes, where known, are discussed. It is hard to be sure that some of the primary pioneer communities listed are not just fortuitous aggregations of plants with no significance, except where a definite relation with substratum or topographic variations is discernible. A detailed map of these communities would be desirable, but time to make such maps at all carefully was not available. The arrangement followed is arrived at purely subjectively, starting with the most extreme pioneer situations and ending with the most advanced vegetation, in a successional sense. It should not, however, be assumed that there is any regular or linear successional series of communities intended. To establish actual dynamic relationships between these communities would take long and detailed study, with repeated visits over a period of years.

1. Cyperus colonies. Occasionally, on gravel bars, at the tops of beaches, and more rarely on interior sand flats, are small groups of usually widely separated tufts of the spreading culms and rather harsh leaves of Cyperus planifolius. That this is a primary community is shown by stands of tiny seedlings on otherwise bare areas. Locally, as on the sand flat at the top of the beach at the north end of Perez, dead tufts

of this sedge were seen. No apparent reason for the dead condition was noted, but perhaps with the extreme drought prevalent here, only slight differences in porosity may result in desiccation of the roots. Colonies of Cyperus are now much more widely distributed than indicated by Millspaugh, who mapped it only from the south end of Perez, where it is still present.

2. Atriplex colonies. At the tops of beaches of fine gravel and sand, and on sand flats in the interior of islets are small rather open patches of Atriplex pentandra, a gray-green bushy herb, clearly tolerant, as are most of its congeners (generally called salt-bush), of high salt concentrations. It seems a bit more widely distributed than indicated by Millspaugh, being abundant on Desertora (Allison) Islet, where he does not show it.

3. Euphorbia mesembrianthemifolia dwarf scrub. One of the most widespread vegetation types is an open dwarf scrub of Euphorbia mesembrianthemifolia, with various, usually minor, admixtures of other plants, especially such herbs as Cenchrus, Portulaca, Cakile, and, occasionally, Atriplex. The substratum is usually small gravel or a mixture of sand and gravel, high enough to be well drained. In places the Euphorbia is largely dead or in poor condition, but mixed with dead or dying plants are occasional healthy green ones. Millspaugh shows this type to be more confined to the peripheries of the islets than it is now, though it is still more commonly found there. There seems to be no indication that this community follows or replaces any other, and it has every appearance of a primary community that would, in an undisturbed situation, be readily replaced by Suriana, or possibly even by Sesuvium or Sporobolus.

4. Portulaca oleracea stands. Locally, on sand and gravel flats, both at the tops of beaches and in the interiors of islets, are open, more or less pure, stands of Portulaca oleracea. This fleshy herb forms depressed circular mats, each made up of one plant, up to 25 or even 30 to 40 cm across. There is no apparent difference between the situations occupied by Portulaca and those of the Euphorbia described above. This is certainly a primary community, probably very short-lived. Millspaugh records only a few individuals of Portulaca scattered among Sesuvium (and Sporobolus). It is much more abundant now.

5. Cakile stands. On beaches, beach ridges, and sand flats just back of beaches are occasional areas of sparse stands of Cakile lanceolata, a somewhat fleshy annual. Almost all mature plants were dead, but shedding mature fruits in July. A few were green and flowering, and locally small seedlings were abundant. This also seems to be a primary pioneer community, confined to substrata of sand or gravelly sand.

6. Open Tournefortia scrub. On Desterrada Islet and on the northwest part of Perez, also on a small sand lobe on the east side of Perez, is a community largely made up of low round dome-like bushes of Tournefortia gnaphalodes, with some admixture of Euphorbia, Cenchrus, Portulaca, and Cakile. This community occupies sandy terraces, dune ridges, and dune fields, and, at least on Perez Islet, seems to indicate land that has recently been added to the islet by deposition of sand. It is not unlikely that the relation with dunes may be the reverse of what might be expected,

that is, that the dunes result from the accumulation of sand by the Tournefortia plants which act as sand traps. These bushes are commonly growing up through a low mound of sand of about the same shape as the bush, with the stems originating at the original ground level beneath the mound. Examination of Perez Islet from the top of the lighthouse shows that the former outline of the islet, that shown on Millspaugh's map, is largely preserved by the present area of Suriana scrub (see below) and the areas occupied by Tournefortia scrub appear to have been added subsequently, as they are clearly outside the periphery of the islet as mapped by Millspaugh. Ground examination of this area shows some indication of invasion by Suriana, suggesting that Suriana will eventually replace the Tournefortia. On Desterrada Islets, this is the principal community, except in peripheral situations. Much of the area is an irregular field of low dunes largely occupied by Tournefortia.

7. Sesuvium mat. On most of the islets are areas, usually not very extensive, covered by closed mats of prostrate, fleshy Sesuvium portulacastrum. These areas are mostly low and very saline, sometimes actually wet at high tide. This vegetation type was, at the time of Millspaugh's visit, by far the most prevalent, covering the larger part of all the islets he mapped. Other plants indicated by him as growing in the areas mapped as Sesuvium suggest invasion. However, in most places the closed Sesuvium community is replaced by open types, so some other factor than invasion and ordinary succession must be involved, as a succession from a closed to an open vegetation would be most unusual. The fact that the areas concerned are now occupied by large bird populations may be of significance. Another fact may be added here. On Desertora (Allison) Islet, some areas of Sesuvium mat are in a very unhealthy condition, and some are completely dead, but with the dead plants mostly still there and intact. These areas are in some cases occupied by nesting frigate birds, but the nests are fairly widely spaced. No other reason for this condition suggests itself, since there seems to be no topographic or other differences between these areas and those where the Sesuvium is healthy and flourishing. On Perez Islet the former extensive Sesuvium area is now completely occupied by open Suriana scrub is the site of an enormous sooty tern rookery.

8. Avicennia swamps. On Pajaros and Perez islets are very small salt-water ponds, cut off from the sea by sand spits, in which Avicennia germinans forms tiny mangrove swamps. The shrubs are at most several meters tall, mostly much smaller, and very young ones and seedlings are plentiful. No other species grow with them, and no such swamps were indicated by Millspaugh, who did not find Avicennia at all. These swamps, though very small, are so conspicuous that they could not have been missed by earlier investigators if they had been present. The local people said that they brought the plants from the swamp on Pajaros Islet to the pond on Perez, but gave no indication of the origin of those on Pajaros. In all probability a single plantlet was washed ashore on Pajaros while the pond was still partly open, or may have been washed into the pond on a high wave, in very recent times, since Millspaugh's visit, giving rise to this vegetation.

9. Tribulus flats. In the interior of the Pajaros and Desertora islets, which serve as rookeries for large numbers of blue-faced boobies, on rather hard packed sand, is a sparse very depressed vegetation of large very open mats of *Tribulus cistoides*, with locally, scattered small mats of *Portulaca*. This occupies areas indicated on Millspaugh's map as *Sesuvium*. Its presence is doubtless in some way related to the birds.

10. Sporobolus virginicus sod. On Pajaros, Chica, and Desertora are areas covered by a closed stand of harsh, wiry salt-grass, *Sporobolus virginicus*. This is generally fairly luxuriant where present at all, usually 20-30 cm tall. Nothing was seen to be invading it. However, its area is now much smaller than indicated by Millspaugh, and it is altogether lacking on Perez Islet, where he showed a large area on the south end and smaller patches in the center. Now these places are entirely covered by *Suriana* scrub. This, however, is open, and how it supplanted the dense grass sod so completely is not clear.

11. Suriana scrub. The dominant vegetation on most of Perez Islet is an open scrub about 1.5 to 2 m tall of *Suriana maritima*. The densely branched, bright green bushes are widely enough spaced that in most places it is easy to walk at will among them. The sand between them is absolutely bare of vegetation. Innumerable sooty terns, adults and feathered out young, occupy the spaces between the plants and roost in large numbers on the bushes themselves. In 1899, according to Millspaugh's map, *Suriana* formed a narrow fringe along the seaward side of the islet, somewhat as it does now on some of the other islets. The position of this fringe is marked now by a sand ridge covered by *Suriana*, that separates the *Suriana* scrub from open sand and gravel flats apparently added to the islet since 1899 and characterized by other vegetation. The curious fact that an open *Suriana* scrub has replaced two types of closed herbaceous vegetation has been alluded to above. It is apparent that, whatever the mechanism, *Suriana* is able to replace all the other natural vegetation types except possibly the *Opuntia*. The ground occupied is mostly sand.

12. Opuntia scrub. Millspaugh indicates a single small patch of what he calls *Opuntia toona*, or *O. tuna*, growing on a small pile of coral heads north of the center of Perez Islet. Now there are two patches, much larger than indicated by Millspaugh, one is approximately the same place, one south of the lighthouse; there is also one patch on the south end of Desertora Islet. The plants seem to be *Opuntia dillenii* rather than *O. tuna*. These fleshy, leafless, very spiny plants form a solid stand about 1 m or less tall, and seem clearly to be spreading at the expense of the *Suriana*. If left to themselves they may eventually occupy the entire islet. The patch on Desertora is a bit less solid, and is the site of a considerable number of Frigate bird nests. The presence of the birds seem to have a bad effect on the *Opuntia*. How the birds go about starting a nest in such an unpleasant situation is not clear, but the nests are dense and substantial enough so that the young birds are not bothered by the spines so long as they stay in the nest.

13. Casuarina groves. Around the lighthouse on Perez, and extending a short distance to the north and south of it, Casuarina equisetifolia trees have been planted, and have reached a considerable size, perhaps 10 meters. Smaller numbers of Cordia subcordata and Coccoloba uvifera shrubs have also been planted and seem to thrive. None of them, however, are reproducing themselves to any extent by seed, and this vegetation type seems to be dependent for its spread, if not for its persistence, on human intervention. The trees are fairly widely spaced and the intervening spaces are occupied by the Suriana scrub that covers most of the rest of the islet. Numbers of frigate birds use for roosts some of the Casuarina trees that are a little distance from the houses around the lighthouse.

Vascular Flora

The tabular arrangement of the plant species gives an idea of the floristic changes that have taken place, with perhaps more reliability than such figures usually have, since the Millspaugh survey was a careful one, as was that by Bonet. It is seen that species have disappeared as well as become established. Water, birds, and people are the principal agencies of dispersal, and most of the plants are well adapted to utilize one or more of these means. Why some species have disappeared is not so readily apparent. Some may have been crowded out as succession progressed. Others, such as Scaevola, may never have been present in sufficient numbers to preclude their disappearance because of accidental elimination of one or two plants. Storms may also have swept certain species away. Finally, some may not have been able to endure the extraordinary droughts that seem characteristic of this island.

In the following tables, E stands for records earlier than Millspaugh's; M for Millspaugh;B, Bonet; F, Fosberg; C. W., Conover, and Welch. 1 indicates that only a single individual was seen on an islet, X, more than one.

List of species	Perez E	Perez M	Perez B	Perez F	Perez C.W.	Desertora M	Desertora B	Desertora F	Pajaros M	Pajaros B	Pajaros F	Chica M	Chica B	Chica F	WD F	ED* F
Syringodium filiforme			X	X	X											
Diplanthera wrightii			X	X	X											
Thalassia testudinarum			X	X	X											
Cenchrus gracillimus								X								
Cenchrus pauciflorus		X					X	X		X					X	X
Cenchrus pilosus			X				X	X	X	X	X				X	
Sporobolus virginicus	X	X	X			X		X	X	X	X	X	X	X		
Cyperus planifolius		1	X	X	X						X					
Boerhavia repens		X														
Atriplex pentandra		X	X	X	X		X	X	X	X		X	X			
Philoxerus vermicularis		X				1										
Sesuvium portulacastrum	X	X	X	X	X			1	1	1	X		X	X		
Portulaca oleracea		X	X	X	X		X	X	X	X	X		X	X	X	X
Cakile lanceolata v. alacranensis		X	X	X		X	X	X	X	X	X	X	X	X	X	X
Tribulus cistoides		1				X	X	X	1	X	X	X			1	
Suriana maritima		X	X	X	X			1		1	X	1	X	X		
Euphorbia mesembrianthemifolia		X	X	X		X	X	X	X	X	X	X	X	X	X	X
Conocarpus erecta	X	X	1	1					1							
Opuntia dillenii		X	X	X	X			X								

	Perez					Desertora			Pajaros			Chica			WD	ED*
List of species	E	M	B	F	C.W.	M	B	F	M	B	F	M	B	F	F	F
Tournefortia gnaphalodes		X	X	X	X			X	1	1	X			1	X	X
Avicennia germinans			X	X						X	X					
Scaevola plumieri		1														
Flaveria linearis		X														
Crinum sp.				X												
Casuarina equisetifolia			X	X												
Cocoloba uvifera			X	X												
Chenopodium ambrosioides (pot)				X												
Portulaca grandiflora (pot)				1												
Jatropha urens (pot)				1												
Terminalia catappa (pot)				1												
Nopalea cochinellifera			1	X												
Cordia sebastena			X	X												
Mentha spicata? (pot)				1												
Capsicum annuum 1 (pot)				1												
Capsicum annuum 2 (pot)				1												
Solanum lycopersicum (pot)				X												
Sesamum indicum (pot)				1												

*WD and ED are West Desterrada and East Desterrada

List of Flowering Plants

The following list includes all the species known to exist on Alacran in July 1961, listed under the names believed to be correct, with citations of specimens seen by me. My own collections have not yet been distributed to herbaria, nor have those of Mr. Bruce Welch. A number of the names used differ from those used for the same species by Millspaugh (1900a, 1900b, 1916). Where Millspaugh's names are regarded as synonyms of those used here, they are listed as such, under the correct names. Where they are considered as misidentifications, they are referred to in the comments, so as not to confuse the reader. An asterisk (*) precedes the names of planted species.

Diplanthera wrightii (Asch.) Asch.

Perez, F 41873.
Submerged marine aquatic, locally common in shallow areas in lagoon and around islets, forming a sod alone or with *Thalassia*.

Syringodium filiforme Kütz.

(*Cymodocea manatarum* Asch.)
Perez, F 41913.
Submerged marine aquatic with terete leaves, local in *Thalassia* sod near islets.

Thalassia testudinarum Koen. et Sims

Perez, F 41872.
Submerged marine aquatic, abundant generally in shallow water on sandy bottoms, forming a dense sod which is the predominant marine vegetation on large parts of the reef.

Cenchrus gracillimus Nash

Desertora, F 41929.
Common locally along lagoon beach ridge and somewhat inland. Differs only slightly from *C. pauciflorus*.

Cenchrus pauciflorus Benth.

Desterrada, F 41919.
Occasional on low sand dunes. This may be the plant reported by Millspaugh (1900) as *C. tribuloides* L. and (1916) as *C. carolinianus* Walt. but it could as well have been the preceding. It now seems to have disappeared completely from Perez Islet, where Millspaugh's collection was made.

Cenchrus pilosus H.B.K.

(*Cenchrus alacranensis* Millsp.)
Pajaros, F 41894; Desterrada, F 41914; Desertora, F 41930.
Local on sand flats and dunes.

Sporobolus virginicus L.

Chica, F 41905; Pajaros, F 41901; Desertora, F 41926.
Forming dense sod on sand flats. In Millspaugh's time this species covered much larger areas than now. On Perez Islet, where it then formed a large part of the vegetation it has disappeared completely.

Cyperus planifolius L.C.Rich.

(Cyperus brunneus Sw.; Cyperus brizaeus Vahl; Cyperus ottonis Boeckl.)
Perez, F 41863, Welch in 1961; Pajaros, F 41895.
Occasional and local on sand flats and at tops of beaches.

*Crinum sp.

Perez, F 41891.
Planted around dwellings; not sufficiently developed for identification, but probably C. asiaticum L.

*Casuarina equisetifolia L.

Perez, F 41876.
Planted in considerable numbers around lighthouse and in central parts of Perez Islet, where they have reached a considerable size but do not seem to establish themselves spontaneously from seed.

*Coccoloba uvifera L.

Perez, F 41878.
Planted near lighthouse.

Atriplex pentandra (Jacq.) Standl.

(Atriplex cristata H. & B. ex Willd.)
Perez, F 41870, 41871, Welch in 1961; Desertora, F 41924.
Local, as scattered individuals, more usually open patches, in sandy and gravelly places.

Sesuvium portulacastrum (L.) L.

Perez, F 41874, Welch in 1961; Pajaros, F 41903; Chica, 41908; Desertora, F 41925.
Abundant locally, forming mats, sometimes very large ones, in low saline places; on Desertora in some areas these mats are dead or apparently dying.

Portulaca oleracea L.

Perez, F 41867, Welch in 1961; Pajaros, F 41902; Chica, F 41909, 41912; Desterrada, F 41917; Desertora, F 41922.
Common to abundant generally in open areas; a form with flowers very large for this species.

Cakile lanceolata (Willd.) Schulz

(Cakile alacranensis Millsp.; C. edentula var. alacranensis (Millsp.) Schulz; C. aequalis L'Her.; C. lanceolata var. alacranensis (Millsp.) Schulz).

Perez, F 41864, 41868; Pajaros, F 41900; Chica F 41910; Desterrada, F 41920; Desertora, F 41932.

Common on upper parts of beaches, beach ridges, and on other open sandy or gravelly areas; our material is all of var. alacranensis, with greatly swollen distal segments to the fruits, but Millspaugh (1900a, b) reported var. lanceolata, first as C. maritima Scop., then as C. aequalis L'Her. This has narrowed merely terete distal segments. The detailed taxonomy of these forms is not yet in a satisfactory condition, so the whole complex is here referred to C. lanceolata.

Suriana maritima L.

Perez, F 41875, Welch in 1961; Pajaros, F 41898; Chica, F 41906; Desertora, F 41928.

Locally forming an open scrub, especially on Perez Islet, where it dominates most of the undisturbed part of the island.

Tribulus cistoides L.

(Tribulus alacranensis Millsp.)

Pajaros, F 41898; Desterrada, F 41916; Desertora, F 41923.

Common on open flats of hard ground, especially where boobies are nesting. The Alacran plants are of a small-flowered form, but since forms with such small flowers may be seen locally in other parts of the world, and since the species is a variable pantropical one, it does not seem advisable to maintain this local population as a distinct species. If a careful study of the variation of T. cistoides were made, there would doubtless be a number of varieties distinguished.

Euphorbia mesembrianthemifolia Jacq.

(Chamaesyce buxifolia (Lam.) Small; Euphorbia buxifolia Lam.)

Perez, F 41862, 41865; Pajaros, F 41899; Chica F 41911; Desterrada, F 41915; Desertora F 41931.

Conocarpus erecta L.

Perez, F 41893.

There seems to be only one bush of this species remaining here, a depauperate specimen with small leaves that so resembles the dominant Suriana that it was missed entirely until Professor F. Bonet called my attention to it. Several are shown in the same locality on Millspaugh's map.

*Nopalea cochinellifera (L.) Salm-Dyck

Perez, F 41879.

Planted, but only one or two individuals, near dwellings.

Opuntia dillenii (Ker-Gawler) Haw.

Perez, F 41892, Welch in 1961; seen also on Desertora.
Forming dense patches, but very local; reported by Millspaugh (1900a, 1916) as O. tuna (L.) Mill.

*Cordia sebestena L.

Perez, F 41877.
A number of trees of various sizes planted near the lighthouse and dwellings, abundantly flowering but almost completely leafless in July.

Tournefortia gnaphalodes (L.) R. Br.

(Mallotonia gnaphalodes (L.) Britton).
Perez, F 41869, 41890, Welch in 1961; Pajaros, F 41897; Chica, F 41907; Desterrada F 41918; Desertora, F 41927.
Abundant in sandy areas on Perez and Desterrada Islets, very rare on Desertora, Pajaros and Chica, only one tiny seedling seen on the latter islet. Millspaugh found one plant on Pajaros and none on Desertora or Chica. Because of the floating mechanism on the fruits, this species and its Indo-Pacific counterpart, T. argentea, are often segregated as a separate genus, called either Messerschmidia or Mallotonia, depending on whether or not the Siberian Messerschmidia sibirica is regarded as also in the same genus.

Avicennia germinans (L.) L.

Perez,F41866; Pajaros, F 41904.
Locally abundant around two small ponds, said to have been brought to Perez from Pajaros; undoubtedly absent from both islets at the time of Millspaugh's visit.

In addition to the 24 species listed above, the following were growing in enclosures protected from the wind and spray, as well as from chickens, by bamboo fences:

*Setcreasea purpurea Boom (F 41886)
*Chenopodium ambrosioides L. (F 41887)
*Portulaca grandiflora Hook. (F 41885)
*Jatropha (Cnidoscolus) urens L. (F 41882)
*Terminalia catappa L. (F 41883)
*Mentha spicata L. (F 41884)
*Capsicum annuum L. (F 41888, 41889, two forms)
*Solanum lycopersicum L. (F 41921)
*Sesamum indicum L. (F 41881)

It is practically certain that none of these would survive exposure to salt and drought on Alacran without special protection and watering.

Plants previously reported from Alacran by Millspaugh, but apparently not found there at present, are Boerhavia repens L., Philoxerus vermicularis (L.) R. Br., Scaevola plumieri (L.) L. (reported as S. lobelia Murr.), and Flaveria linearis Lag.

Terrestrial Vertebrates

July is a poor month to see a large variety of birds on Alacran, though a few species are present in large numbers and several nest at this season or just before. In all, only 13 species of birds were seen during a visit of over a week. These all seemed to be resident birds. Doubtless a much longer list could be observed during migration seasons.

The following birds and reptiles were all seen during the first week in July 1961. A few of the species had been recorded earlier by Kornicker and associates (1959), and several by Dampier (1699). Birds are also listed by Kennedy (1917) and Paynter (1953, 1955) but their records will not be discussed here. The two mammal records are included as they may represent the entire mammal fauna in pre-lighthouse days.

Mammals

Rattus sp. "large rats"

Dampier (1699, 1931 ed. p. 143) records "large rats, which are in great plenty." No rats were seen in 1961 on any of the islets. They may have been eliminated by the dogs and cats of the lighthouse staff, but this does not seem likely. Other evidence suggests that a severe storm may have swept the islets, eliminating the vegetation, subsequent to Dampier's visit. The rats may well have been eliminated also.

Monachus tropicalis (Gray) West Indian Seal, West Indian Monk Seal

Alacran was formerly an important habitat of this tropical seal. Dampier (l.c., pp. 145-146) speaks of the abundance of seals on Alacran and gives an account of an expedition from Jamaica to prepare seal oil. In recent years, no seals have been seen on the atoll, and it is feared that these interesting creatures may now be extinct. Raymond Gilmore made a search for them over their former range a few years ago but failed to find any. However, he told Gordon Gunter (1954) that they had been reportedly seen on Alacran as late as 1948.

Birds

Sula dactylatra Lesson Blue-faced booby

Two were seen flying by Perez Islet on first day, but none were nesting or even roosting on Perez. On July 4, 8 or 10 were seen on Chica Islet, mostly with downy to partly feathered out young, one parent staying with each bird. Two of the young seemed newly hatched, scarcely even downy yet. One bird had two eggs. One hundred or more were seen on Pajaros Islet, mostly with young in various stages from newly hatched to almost grown. Two were seen with eggs, one with one, and one with two. An enormous number were seen on Desertora Islet, from the lagoon; later many hundreds were examined on the ground, with eggs and young in all stages. Nests were about 2 m apart.

From Dampier's account (1699, 1931 ed., pp.143-144) boobies must have been more numerous in 1675 than now, though their behavior and the fact that they occupy definite territories on the islets have not changed.

Sula leucogaster (Boddaert) Brown booby

Six were seen flying north of Desertora in forenoon of July 5. In afternoon, 50-60 were in air over Desertora Cay. It is not clear where they live. One was seen on the ground on Desertora on July 6.

Fregata magnificens Mathews Frigate bird

Hundreds of these great birds roost on the Casuarina trees on Perez Islet during the daytime. On July 5, a large number were on the ground and on some old pilings off the lagoon beach of Desertora Islet. Many were nesting on the ground there; the nests are very low mounds of twigs, in thin, dead, or half dead Sesuvium mats. The young were fully feathered out but not yet flying. Many dead young frigate birds were seen. About 75 nests were in a cactus patch near the southeast corner of the cay.

Dampier (l.c., p. 144) gives an excellent account of "Men-of-War-Birds" on Alacran, reporting them in great numbers and recording their habit of piracy, robbing the boobies both young and old, of their already swallowed fish. Possibly this is the earliest account of this phenomenon.

Florida caerulea L.? Little blue heron

A small dark heron, seen on one of the lagoon bars toward the south end of Perez Islet, may have been this species. Its behavior resembled that of the reef heron (Demigretta sacra) on Pacific coral islands.

Arenaria interpres L. Ruddy turnstone

A small flock of turnstones were observed on Perez Islet, 5 birds on Chica, and 2 on Desertora, running and flying along the beaches, their habits much the same as on Pacific atoll beaches.

Castrophorus semipalmatus Gmelin Willet

One was seen on the lagoon beach of Pajaros and another on the lagoon beach at East Desterrada Islet.

Larus atricilla L. Laughing gull

On July 4, 20-30 were seen on Chica Islet. A small nest, of Euphorbia mesembrianthemifolia, in a mat of Portulaca oleracea, about 15-18 cm across and containing a dull gray egg with irregular blackish-brown spots, probably belonged to a pair of these, as they flew around making much noise when it was approached.

One gull was seen on Pajaros Islet, several were with a flock of royal terns on East Desterrada, and several were flying over Desertora Islet.

Thalasseus maximus (Boddaert) Royal tern

One was seen flying near Perez Islet, none were resting or nesting there. On July 4, 20 or 25 were seen sitting on a small sand horn on Chica Islet. On July 5, a number were over the lagoon north of Desertora Islet, all flying toward Desterrada. An enormous flock, of perhaps several thousand birds, were sitting on the sand on a low beach ridge on the north east side of East Desterrada, protesting when scared up, mostly notwanting to leave. Eleven large gray eggs with black spots, in slight depressions in sand on the berm at the top of the seaward beach, probably belonged to some of these birds, as they made a tremendous commotion when the eggs were approached.

Sterna hirundo L. Common tern

A considerable number of light backed terns with black bills, which must have been this species, were seen on East Desterrada, mixed with the large flock of royal terns described above.

Sterna fuscata L. Sooty tern

An enormous colony of these graceful birds occupies the greater part of Perez Islet outside the portion immediately around the lighthouse and weather station buildings. Almost full grown young, fully feathered out but not quite able to fly, were seen in great numbers. These young had dark breasts, pale gray anal parts, black backs barred with buff to white on feather tips. When a person walked through the area these young birds scrambled frantically to get away through and under the bushes, and clouds of adults flew up. The sooty terns rest in hundreds on the Suriana bushes, but in tens of thousands on the ground between them. One egg was seen on the sand on a seaward sparsely vegetated sand terrace near the south end of the islet. At night the sooty terns were still roosting on the ground and in the Suriana bushes, making less noise than during the day. A strong light scares them up but they fly with much less sureness than in daytime. On July 3, clouds blew over and a very few drops of rain fell, not enough to be registered by the rain gauges. This occasioned a terrific clamor among the sooty terns, far more than the normal level of noise, and great numbers of the birds left the ground and flew around in great confusion and excitement. Some immature birds, with varying amounts of gray on under parts, were seen flying over the lagoon north of Perez Islet and adults were common in the air around Perez. None were observed on the ground anywhere except on Perez Islet. People resident on Perez say the terns leave the island in September and return in February.

The "Egg-Birds" recorded by Dampier (l.c., pp.143-144) were probably sooty terns. He says: "The Egg-Birds, tho' they are many, yet being but small take up little room to the rest. Yet in that little part which they inhabit they are sole Masters, and not disturbed by their Neighbours." This does not correspond well with the present situation, where the sooty terns are "sole masters" of almost the entire Perez Islet and far more numerous than any other bird on the atoll. The difference may of course be due to a difference in season, as Dampier was there in the fall, probably October.

<u>Sterna</u> <u>anatheta</u> Scopoli — Bridled tern

Many of these were seen on July 5 in a mixed flock with black terns sitting on the east spit of West Desterrada Islet.

<u>Chlidonias</u> <u>nigra</u> (L.) — Black tern

Many were seen in a mixed flock with bridled terns sitting on the east sand spit of West Desterrada Islet.

<u>Anous</u> <u>stolidus</u> L.? — Common noddy?

Many noddies were seen on Perez Islet, apparently the common noddy but rather light colored (compared to Pacific birds), nesting in <u>Suriana</u> bushes (some in <u>Casuarina</u>). The nests were of <u>Suriana</u> twigs, very bulky and poorly formed, but some fully 1 meter tall and standing on the ground. Some of the nests were ornamented by as many as 25-30 bivalve shell halves, most had none. This seems to be a matter of individual taste on the part of the birds. A few had eggs or newly hatched young, while some had fully feathered out young. The large nests are in striking contrast to the small flimsy collections of twigs that serve as nests for the common noddy of the Pacific, as seen in the Northern Marshalls. The noddies on Perez mingle freely with the sooty terns in the same area. Neither noddies nor their nests were seen on the other islets.

<u>Reptiles</u>

<u>Mabuya</u> <u>mabuya</u> (Lacepede) — Skink

This lizard is apparently rare, as it was only seen twice, both times on Perez Islet. A mature specimen was collected on a coral gravel ridge just back of the beach on the north end of the islet. It was identified by Drs.Doris Cochran and Walter Brown, and is deposited in the U. S. National Museum. A small specimen of what is probably the same species was found in a building near the lighthouse by Professor F. Bonet. Mr. Hoskin stated that he had seen these lizards occasionally during his earlier visits to Alacran.

<u>Chelone</u> <u>mydas</u> (L.) — Green turtle

Two egg pits were seen on a sand lobe on south end of Perez Islet, a number of others on the west sand ridge of Pajaros near the north end, and several more on Desertora along the seaward terrace back of the beach. Six great turtles had been captured and were on their backs in a shed on West Desterrada Islet on July 5.

Terrestrial invertebrates: Insects

The following list of insect identifications was furnished by the U. S. National Museum.

Formicidae

Paratrechina longicornis (Latr.), det. M. R. Smith

Coccinellidae

Naemia seriata (Melch.), det. E. A. Chapin

Tenebrionidae

Blapstinus sp., det. T. J. Spilman

Curculionidae

Dryotribus mimeticus Horn
First record from Mexico, Yucatan, det. R. E. Warner

Tethinidae

Rhicnoessa sp.

Muscidae

?*Lispocephala* sp.

Sarcophagidae

Tricharaea femoralis (Schin.), det. C. W. Sabrosky

Hippoboscidae

Olfersia spinifera (Leach), det. A. Stone

Pentatomidae

Murgantia histrionica (Hahn)
Microporus obliquus Uhler

Lygaeidae

Exptochiomera sp.?
Nysius sp., det. R. C. Froeschner

Myrmeleontidae

Psammoleon cf. *bistictus* (Hag.), det. O. S. Flint

Coccoidea

Phenacoccus sp., on cultivated pot plant. Det. H. Morrison

Acrididae

Trimerotropis pallidipennis Burm.

Blattidae

Periplaneta americana (L)
Panchlora sp.

Gryllidae

Cycloptilum sp., det. A. B. Gurney

The collection also included Histeridae, Sarcophagidae, Thysanura and spiders which were not identified.

Comparison between Alacran and Pokak Atolls

One of the principal purposes of visiting Alacran was to compare it with the Pacific atolls with which I am familiar. It was soon evident that the Pacific atoll in my experience most comparable with Alacran is Pokak (Taongi), the northernmost of the Marshall Archipelago (Fosberg 1955, 1956, 1957). They are both completely in the trade wind belt, not exposed to doldrum influence to any significant extent. Alacran is at 22°30'N latitude, Pokak 14°35'N. Both are dry, though adequate rainfall records are not available for comparison.

Detailed lists of species are not available either except for vascular plants and land vertebrates, and the bird lists cannot be compared profitably because they were collected at different seasons. Nor are analyses, either chemical or mechanical, of the soils and sediments available for Alacran. It would perhaps be profitable to have some made for comparison with those on hand from Pokak and other Marshall Islands. It would be of great interest to study the Pokak marine biota to determine the role of the various species in the reef community, as Kornicker and Boyd (1962) have recently done for that of Alacran.

The following tabular comparison is mostly of very general features. Some of these are single items, others may be regarded as integrations of many components. The list may only be regarded as a start toward a definitive comparison, but may be indicative of the degree of similarity or dissimilarity.

ALACRAN	POKAK
Reef and lagoon features	
Orientation north-south	Same
Total length, 25 km	Total length, 18 km
Total width, 13 km	Total width, 8 km
Maximum depth of lagoon, 23 m	Maximum depth of lagoon, 15 m
Lagoon open on a large part of leeward side	Lagoon closed except for a tiny leeward channel
Lagoon level changing with tides	Lagoon level almost constant
Windward reef crescent-shaped	Same
Algal ridge none	Algal ridge well developed
Niggerheads none	Niggerheads abundant
Reef platform sandy, evident only on windward side, where it is covered by an incomplete pavement of slabby boulders, an accumulation of these on the windward edge exposed at lowest tides	Reef platform flat, a completely consolidated algal pavement, probably a planation surface enamelled by calcareous red algae
Outer slope of leeward reef gradual, shelving	Outer slope of leeward reef abrupt, steep
Lagoon reefs abundant, forming a network extending through most of the lagoon	Lagoon reefs few, mostly parallel to main reef, concentric to it
Alcyonarians abundant on reefs	Alcyonarians rare or absent
Calcareous red algae not making up a large proportion of reef community	Calcareous red algae abundant

Islets

ALACRAN	POKAK
Islets all on leeward side of atoll, well distributed from end to end	Islets all on southeast quadrant, on windward side
Islets with no evident reef-rock platform	Reef-rock platform prominent, mostly somewhat under 2 m above mean low tide, few humps to 3 m or more
No consolidated rock on islets, neither reef-rock nor beachrock	Reef-rock and beachrock abundant
Sediments on islets mostly sand and small gravel	Sediments from sand to boulders, mostly coarse
Boulder ridges none, low sand beach ridges and dune ridges general	Boulder ridges on most windward coasts, locally on lagoon side, sand ridges and dune ridges only very local
Large boulders on islets none (except a few from ballast)	Large boulders on islets common
Ground water saline	Same

Vegetation

ALACRAN	POKAK
Thalassia beds abundant on sandy bottoms	*Thalassia* or other sea-grasses absent
Algal crusts on sand none except where wet by salt water	Algal crusts general on dry open sand
Algal discoloration of dry coral rocks almost none	Algal discoloration of dry coral rocks general and conspicuous
Native vegetation low, semi-arid in aspect, maximum height about 2.5 m.	Same, but maximum height 5-7 m
Principal native vegetation types: 1. Open scrub of *Suriana*; 2. open scrub of *Tournefortia*; 3. Mangrove swamp; 4. open dwarf scrub of *Euphorbia*; 5. closed *Sporobolus* sod; 6. *Sesuvium* mat	Principal native vegetation types: 1. Open scrub forest of *Tournefortia*; 2. closed scrub forest of *Pisonia*; 3. closed scrub of *Scaevola*; 4. open scrub of *Sida*; 5. shrub-savanna of *Lepturus* with *Sida*; 6. *Lepturus* bunch grass.

Land Biota

ALACRAN	POKAK
Birds (resident)	Birds (resident)
6 terns	7 terns
1 gull	3 boobies
2 boobies	2 tropic birds
1 frigate bird	1 frigate bird
1 heron	1 heron
2 shore birds (occasionally resident)	4 shore birds (occasionally resident)
	1 shearwater
Mammals	Mammals
1 rat (formerly)	1 rat
1 seal (formerly	
Reptiles	Reptiles
1 lizard	1 lizard
1 turtle	
Vascular plants	Vascular plants
19 native species	9 native species
3 introduced species established	No exotics (coconut was introduced but did not live)
2 others perhaps able to persist without protection	

Perusal of this table shows that, except for features that characterize all atolls, and which are not included, the differences between these two atolls are perhaps more important than the similarities. If Alacran were compared with atolls in wetter climate belts, the differences would be even more impressive. However, Alacran is only one of the Caribbean atolls, and no generalization is possible until a substantial sampling of others have been compared with Pacific atolls in similar climatic situations. Also comparisons of much more detailed and exact features are needed.

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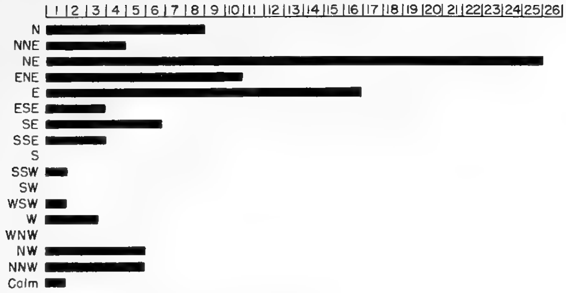
Flora marina de los alrededores de la isla Perez, Arrecife Alacranes, sonda de Campeche, Mexico.
Ann. Escuela Nac. Ci. Biol. 10: 10-22, 1961.

WIND GRAPHS

JANUARY 1959



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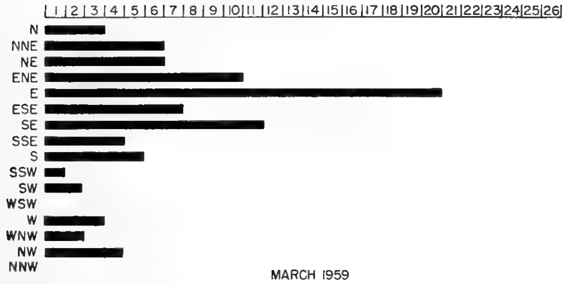

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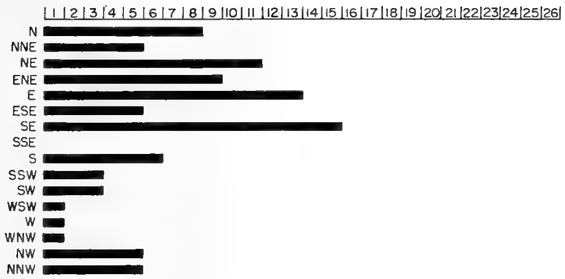

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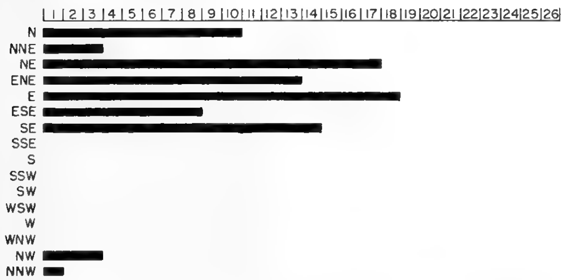

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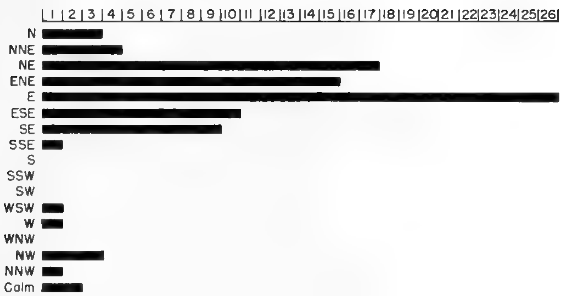

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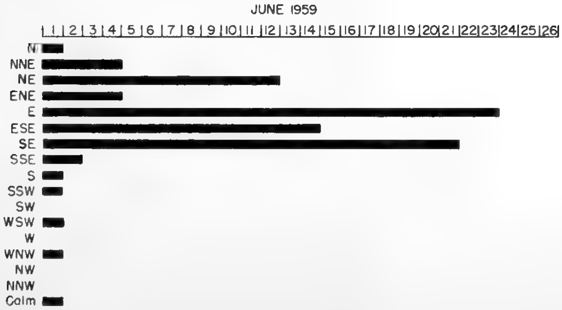

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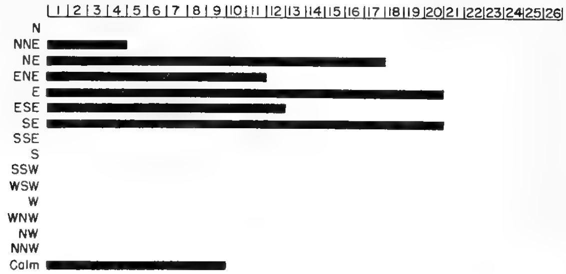

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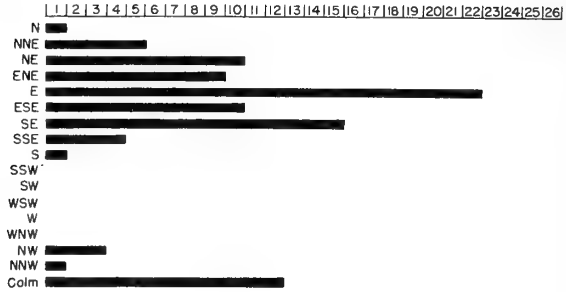

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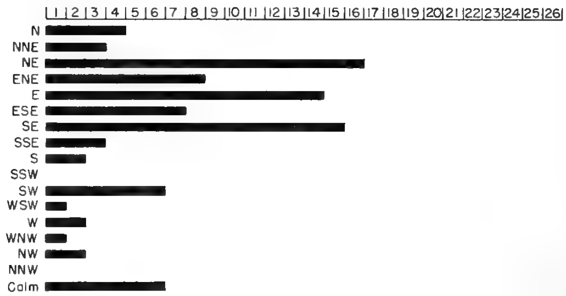

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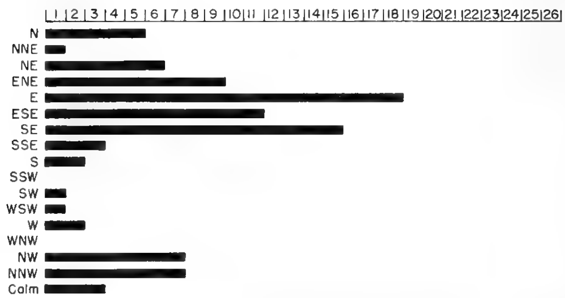

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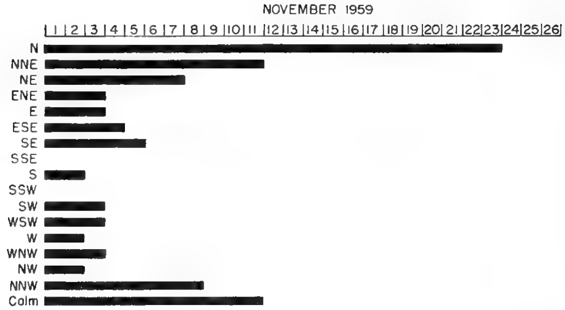

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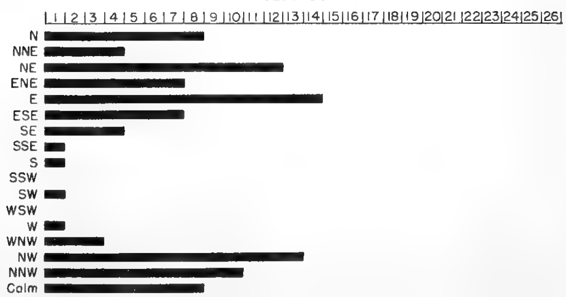

WIND GRAPHS

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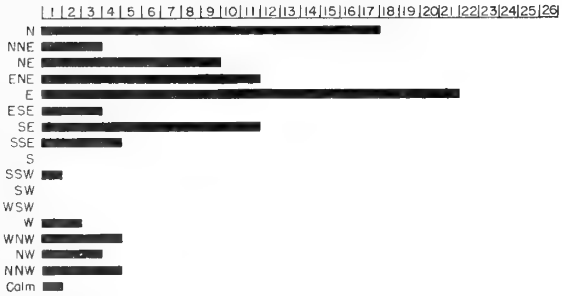

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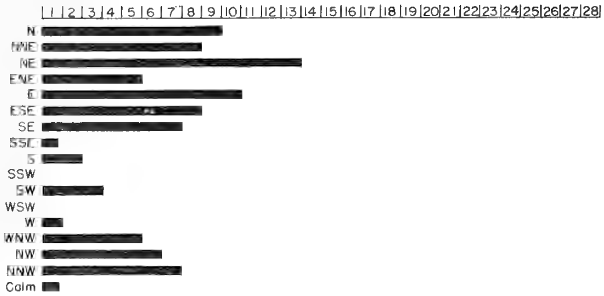

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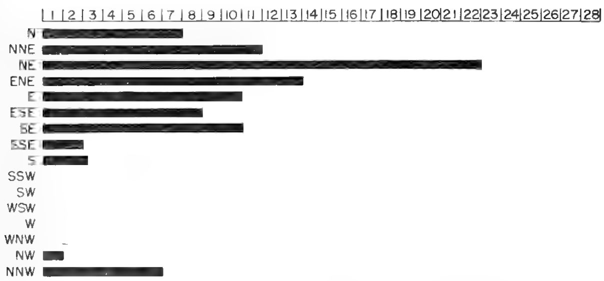

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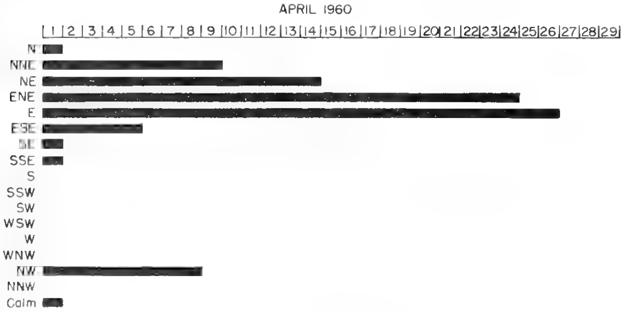

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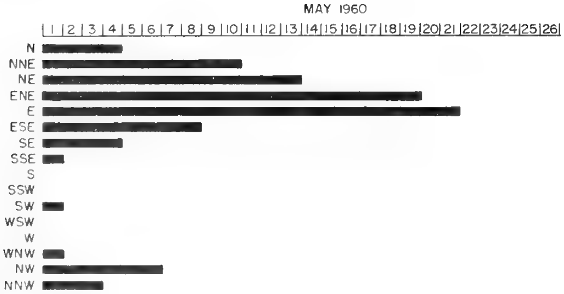

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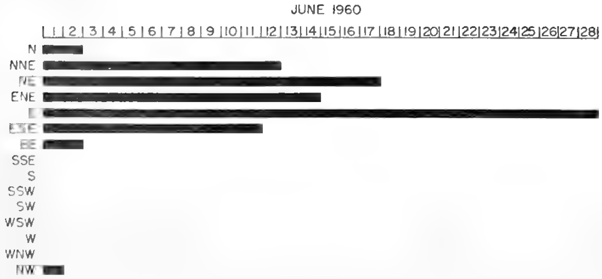

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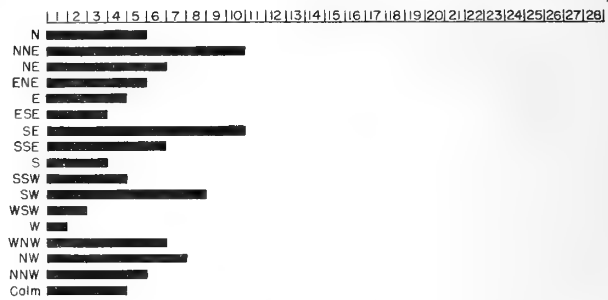

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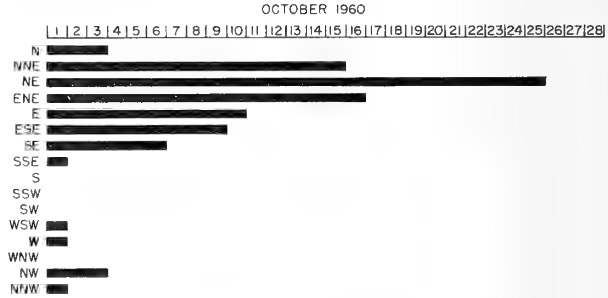

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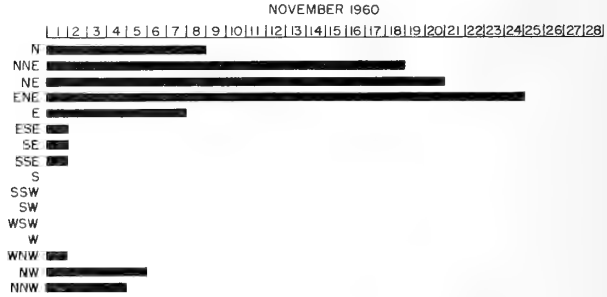

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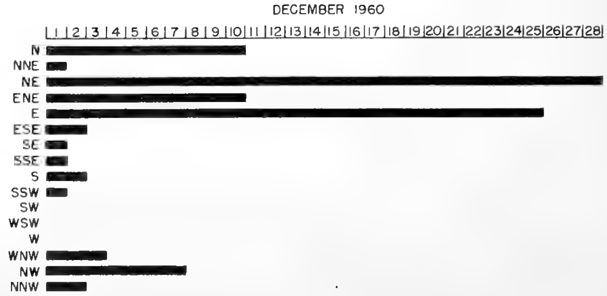

WIND GRAPHS

JANUARY 1961

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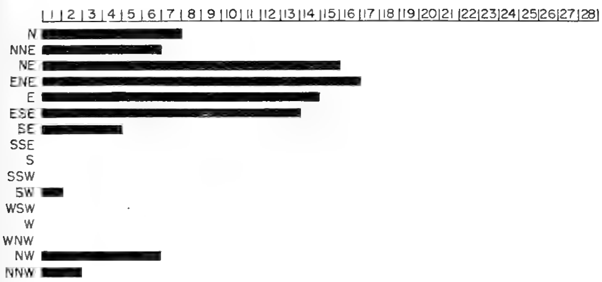

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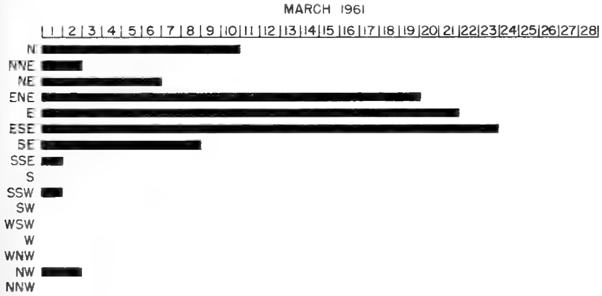

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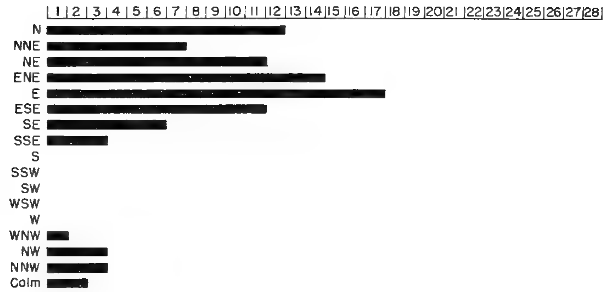

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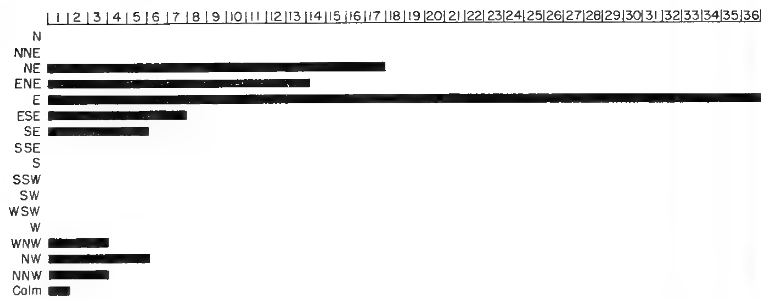

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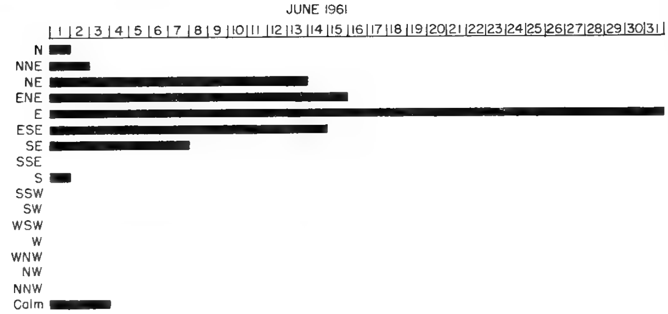

Daily Rainfall (in millimeters)

1959	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	20	0	5	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	21	0	0	0	0	0	0	0	0	0	0	0
6	8	1	8	0	0	0	0	0	0	9	0	0
7	0	0	0	0	0	0	0	0	0	0	3	0
8	18	0	2	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	9	0	0
10	0	0	0	0	0	0	0	0	6	0	0	0
11	0	1	0	0	0	0	0	0	999*	1	0	0
12	0	0	0	2	0	0	0	0	0	0	9	0
13	0	0	0	1	0	0	0	0	0	0	0	0
14	0	0	0	0	4	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	2	0	0	0
16	0	0	0	0	0	16	0	0	0	0	0	0
17	0	0	0	4	0	0	0	0	0	0	0	0
18	0	0	0	0	0	18	0	0	7	3	4	0
19	0	0	5	0	6	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	22	0
21	0	20	0	0	0	0	0	0	0	0	3	0
22	7	0	0	0	0	0	0	0	8	0	0	0
23	0	0	0	0	0	0	0	0	0	1	0	5
24	0	0	0	0	0	0	0	0	20	0	0	0
25	1	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	1	0	0	0	0	0	0	0
28	0	4	0	0	0	0	0	0	0	0	0	0
29	5		0	0	0	0	0	5	1	0	0	0
30	0		0	0	2	0	0	0	0	0	0	0
31	0		0		0		1	0		0		0

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* The gauge overflowed

Daily rainfall (in millimeters)

1960	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	0	0	0	0	0	0	0	0	0	1	0	0
2	0	0	0	0	6	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	2	8	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	1	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	3	0	0	0	1	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	25	0	0
10	0	0	0	0	0	0	40	0	0	3	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	3	0	0	0	0
13	0	0	0	0	0	4	0	6	0	0	0	0
14	0	0	0	0	0	0	0	0	3	0	0	0
15	0	0	0	0	0	0	4	0	0	0	0	6
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	6	0	0	2
19	0	0	0	0	0	2	0	9	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	20	0
23	0	0	0	0	0	0	0	0	1	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	999*
27	0	0	0	40	1	0	0	0	21	1	0	0
28	0	0	0	0	0	0	0	0	28	0	0	0
29	0		0	0	0	0	0	0	0	0	0	0
30	0		0	0	0	0	0	0	7	0	0	0
31	0		0		0		0	0		19		0

----

* The gauge overflowed.

Daily Rainfall (in milimeters)

1961	Jan.	Feb.	Mar.	Apr.	May	June	July
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	1	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	9	0	0	0	0	
8	0	0	0	0	0	0	
9	999*	0	0	0	0	0	
10	0	0	0	0	0	0	
11	0	0	0	0	0	0	
12	0	0	0	0	0	3	
13	0	0	0	0	0	0	
14	0	0	0	0	0	0	
15	0	0	0	0	0	0	
16	0	0	0	0	0	0	
17	0	0	0	0	0	0	
18	0	0	0	0	0	0	
19	0	0	0	0	0	0	
20	0	0	0	0	0	0	
21	0	0	0	0	0	0	
22	0	0	0	0	0	0	
23	0	0	0	0	0	0	
24	0	0	0	0	0	0	
25	0	29	0	0	0	0	
26	0	0	0	0	0	0	
27	0	0	0	0	0	0	
28	0	0	0	0	0	0	
29	3		0	0	0	0	
30	0		0	0	0	0	
31	0		0		0		

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* The gauge overflowed

ATOLL RESEARCH BULLETIN

No. 94

Atoll News and Comments

Issued by

THE PACIFIC SCIENCE BOARD

National Academy of Sciences--National Research Council

Washington, D. C.

December 15, 1962

Atoll News and Comments

It is hoped that we can continue this series, gathering together, from time to time, items that we think may interest the readers of the Bulletin, as well as including brief observations, short notes of one page or less, that it would be impractical to issue as separate numbers. Signed or unsigned reviews or notes are welcome (unsigned ones will be used if they do not contain libellous or uninteresting material and if they are not likely to misrepresent the editors' views). If it is important that announcements be phrased in a particular manner, it will be better to send them in with the exact wording desired.

Current events

Christmas Island:

As everyone knows from newspaper accounts, Christmas Island has been, during the past summer, the site of a new series of atomic weapons tests. Undoubtedly some scientific work on the atoll has been conducted in connection with these tests, but we have little information on it. An announcement in Pacific Science Assaociation Information Bulletin 14(3): 9, 1962 says that the fisheries and oceanographic research vessel Charles H. Gilbert, from Honolulu, has been "participating in biological surveys connected with the nuclear weapons tests at Christmas Island in May," in cooperation with the AEC and the Laboratory of Radiation Biology of the University of Washington. They are collecting samples of animals to "examine them for possible effects of the nuclear tests."

Due to the test series, the planned investigation of the ecology of the sooty tern colony there, noted in ARB 84, p. 1, has had to be abandoned, according to a communication from Philip Ashmole, of Oxford University, who was planning the expedition. It seems a great pity that an intensive investigation of Christmas Island could not have been undertaken before the test series started, as it is certainly one of the most interesting of all coral atolls. The amount of damage it is suffering as a result of the tests is not known but is doubtless considerable.

The Natural History Society (Christmas Island) and its Bulletin: We have secured, thanks to the kindness of Major M. D. Gallagher, a set of the Bulletins of the Society through no. 11 (lacking no. 2, which was superseded by no. 9). This rare publication contains many observations, principally on the birds of the island. The observations on birds have been adequately summarized by Maj. Gallagher in the Ibis (Bird notes from Christmas Island, Pacific Ocean, Ibis 102: 489-502, 1960); this paper includes also a description of the island, with map, notes on climate and vegetation and some mention of some of the island fauna. A description of the Bulletin may be of interest and is given below.

"The Society was formed on Saturday 6 Sep 58 for the purpose of fostering interest in wild life on Christmas Island." As far as we have been able to find out, it did not long survive the departure from Christmas I. of its founder and moving spirit, Maj. Gallagher. During its short existence, however, the Society issued 11 mimeographed or offset Bulletins. As far as we are aware, two sets of these are available outside the island,

one at the Bishop Museum, and one in the files of the Pacific Vegetation Project. The contents of these Bulletins will be listed below, and certain portions not covered in the Ibis article quoted with the permission of Major Gallagher. Besides the publication of the Bulletin, the activities of the Society consisted in meetings, held at one or two weeks interval, with discussions, showings of photos and films, and in field trips, including visits to the three bird sanctuary islets which were established to protect bird life when the British tests of atomic devices were started, and which could be visited only by special permission of the Base Commander.

The material in the Bulletins is arranged under various headings, which are numbered consecutively from one issue to the next. These numbers and headings will be used below.

Bulletin No.1, 17 Sep 58

1. The Society
2. Bulletins
3. Visit to Motu Upua - 14 Sep 58. (This is one of the bird sanctuaries, and notes on various birds are included in this paragraph).
4. Meeting 15 Sep 58
5. Coming events
6. Membership (17 Founding members are listed).

Bulletin No. 2

(This Bulletin was superseded by No. 9, and we do not have a copy. It consisted in a list of Christmas Island birds.)

Bulletin No. 3, 14 Oct 58

Introduction

8. Cook Island - 20 Sep 58 (A field trip to this bird reserve islet, with notes on birds observed).
9. Manulu Lagoon- 20/21 Sep 58. Field trip to islets in this large lagoon.
10. Meeting - 29 Sep 58
11. Meeting - 6 Oct 58 (Includes recent observations on birds).
12. Observations - 25 July to 13 Aug 58 (on birds).

Bulletin No.4, 10 Nov 58

13. Meeting - 21 Oct 58
14. Mota Tabu - 25 Oct. 58 (A field trip to this bird reserve, with notes on birds observed).
15. Mota Tabu - 2 Nov 58
16. Meeting - 3 Nov 58 (Birds and plants were discussed). To paragraph 20.

Bulletin No. 5, December 1958

21. Meetings
22. Cook Island - 16 Nov 58 (notes on birds seen).
23. Malden Island - 31 Oct 58 (see below)
24. Mota Tabu - 9 Nov 58 (Field trip, notes on birds).
25. Duck (notes on various ducks observed in patches of partly salt water near Main Camp in November).

26-28. Notes on various birds.

29. Manulu Lagoon - Nov 58 (Several visits in November, with notes on birds seen).
30. Mota Upua - 30 Nov 58 (Field trip, with notes on birds).

Bulletin No. 6, January 1959

This Bulletin is offset, and is not numbered like the others, but consists in an introduction, and illustrated accounts of 20 plants, with Latin, English and Gilbertese names. See below for list of species.

Bulletin No. 7, 2 Feb 59

Introduction
31. Meetings
32-43. (Extensive notes on various birds).

Bulletin No. 8, 18 March 1959

44-58. (Extensive notes on birds observed in Dec. 58 to March 59).

Bulletin No. 9, March 1959

This Bulletin is offset, and is not numbered like the others. The title is: Bird life on Christmas Island. It includes: Introduction, Topography of a bird (with drawings and list of parts), and descriptive notes, with illustrations, on 27 species of birds, listed under the headings Sea birds, Resident land birds, and Migratory birds. There is also a sketch-map of the island.

Bulletin No. 10, 20 April 1959

59. The weather (includes a table of rainfall for several years, which is reproduced and expanded in the Ibis article).
60. Visit to Mota Tabu - 4 April 59 (notes on birds seen).
61-78. (Notes on birds observed and their habits).

Bulletin No. 11, 1 June 59

79. The Secretary (announces the departure from Christmas of Maj. Gallagher).
80. The weather
81. Visit to Mota Tabu - 2 May 59 (notes on birds observed).
82. Cook Island - 17 May 59 (notes on birds observed).
83. Other reports (other observations of birds).

Excerpts from the Bulletins

Bull. 4, par. 13:

Manta ray: Several manta rays reported seen in the sea off the S.E. point from a helicopter. A leopard ray was photographed in the lagoon.

Dead birds: Many dead birds, mostly shearwater, have been found along the SPAL road. The cause of their death is not evident.

Bull. 4, par. 14:

Large number of dead birds were found (on a visit to Motu Tabu). Many of these had obviously become caught in the undergrowth; these included blue-grey noddies and petrels.

Bull. 4, par. 16:
It was reported that there were a large number of dead fish near the SPAL road. These are believed to swim into an island lagoon on a very high tide to spawn, but owing to recent lack of rain and the low level of water in this lagoon the fish have been unable to regain their freedom in the sea. Over 1500 have been buried or burnt but there are many more. The birds will not touch the dead fish.

Bull. 4, par. 20:
Plants: It has been suggested that members might like to collect seed specimens which drift upon the beaches, such as the Bay of Wrecks as they serve as valuable records of the disperal of ocean-borne seeds.

Bull. 5, par. 23:
Malden Island - 31 Oct 58. (This paragraph reproduced in its entirety).
Three members spent about 4 hrs on the Island on 31 Oct 58 arriving at midday and leaving at 4 pm (CI time) and observed the following birds some of which were photographed.
White tern: 4 seen in flight.
Wandering tatler: 2 seen feeding at edge of water near reef.
Red tailed tropic bird: 1 seen in flight only.
Blue faced booby: About 10 of these birds were seen on the ground along the shore of the lagoon. Several more were seen in the air. Some of the birds had single eggs and others had young birds probably a few months old, on the nest which consisted in all cases of a shallow depression in ground.
Frigate bird: None seen close to though a large flock of black birds, believed to be Frigate birds, were seen as aeroplane circled Island after take off.
Mice: Certain very small type of mouse seen in abundance about 1"-2" long.
Wild pig: Reported to still exist in very small numbers on Malden Island but none were seen.
Fish: A few fish about 9-12" long seen on the reef, black and bright scarlet.
In general there appeared to be few birds on the Island, but this may have been due to the time of day. Although the Island is green it is believed there are now only about 2 bushes and 3 trees! Some plants were brought back and identified as:-
Boerhavia diffusa, a prostrate vine-like herb.
Portulaca lutea, an erect pig weed or purslane with yellow flowers and fleshy stem.
Sesuvium portulacastrum, a prostrate 'seaside-purslane' with finger like leaves and mauve flowers.
Lepturus repens, 'bunch' or 'wire' grass with stiff flower stalks.
Tribulus cistoides, a trailing herb with yellow flowers and thorny fruit like sets of miniature cow's horns.
These are common on parts of Christmas Island.

Bull. 6: Vegetation on Christmas Island.
After a brief Introduction, 20 plants are listed, described and illustrated. They are:
1. Pandanus tectorius (Screw pine) (Te Kaina): A few trees planted at Four Wells, London Village and Poland.
2. Lepturus repens (Bunch grass). Most common perenial grass on Island.

3. Digitaria pacifica
4. Eleusine indica
5. Eragrostis amabilis
6. Cenchrus echinatus
7. Cocos nucifera. Now over 600,000 palms.
8. Boerhavia diffusa (also B. tetrandra and B. hirsuta) (Te Wao). Widespread.
9. Pisonia grandis (Buka tree). Some trees on Mota Tabu and at SE corner.
10. Portulaca lutea (pigweed) (Te Boi)
11. Portulaca oleracea (purslane)
12. Sesuvium portulacastrum (seaside purslane). On mud flats and near water holes.
13. Cassytha filiformis (laurel dodder) (Te Ntanini)
14. Tribulus cistoides (puncture vine) (Te Maukinikin). Widespread.
15. Suriana maritima. Grows extensively over the lagoon mud flats.
16. Sida fallax (te Kaura) (also Sida cordifolia). Widespread, often as thickets.
17. Heliotropium anomalum (Beach heliotrope). Extensively behind beaches and elsewhere.
18. Messerschmidia argentea (Tree heliotrope) (Te Ren). Along beach crests and elsewhere.
19. Scaevola frutescens (Beach scaevola) (Te Mao).
20. Pluchea odorata (Sour bush) (Te Aronga). Amongst coconut palms near JOC, airfield and elsewhere.

Blasting on Central Pacific Reefs

We are informed by Capt. W.M.R. Addison, of the Royal Engineers, of a current program of blasting boat channels through the reefs of a number of atolls in the Gilbert, Ellice and Phoenix groups. Plans call for channels 15 feet wide and 1 to 4 feet deep, also for some blasting out of coral heads in at least the Tarawa Lagoon. The atolls included in the program are Nui, Tamana, Nanumanga, Arorae, Beru, Aranuka, Marakei, Tarawa, Gardner, Hull, and Sydney, and possibly Maina, Makin, Niutao or Nukulaelae. This work is under way at present and is expected to be finished by December 1, 1962. Unfortunately it was started without any preliminary ecological work at all, so there will be another case of difficulty in measuring the changes brought about by man's activity. In this way, only spectacular or disastrous consequences are ever confidently ascribed to their causes.

Capt. Addison has sent a copy of a report containing a number of very interesting observations made at Beru, Gilberts, and has promised to gather data of a number of sorts on the islands to be visited later in the program. We hope to be able to utilize the pertinent part of this information in a later issue of Atoll Research Bulletin.

Clipperton Island: Errata and addenda, ARB 86

In Bulletin 86, Table 3 (after p. 24), instead of MacDonald, read McDonald. Column "% observations reporting precipitation ...", for December should read "Clipperton between 25 & 30% isograms;" for January, should read "Clipperton between 15 & 25% isograms."

Since the publication of ARB 86, the following papers have come to hand:

Balech, E.
Glenodinium cristatum, sp. nov. (Dinoflagellata).
Neotropica 7(23): 47-51, 1961.
This is the Glenodinium sp. mentioned p. 92, described from Clipperton (also mentioned in Sachet, 1962, Flora and vegetation of Clipperton Island, p. 268).

Bennett, Raine
The Madonna of Passion Isle.
American Weekly, 10-11, Jan. 10, 1954.
Fanciful account of the 1917 rescue of the Mexican women and children.

Chace, Fenner A., Jr.
The non-brachyuran decapod crustacea of Clipperton Island.
Proc. U. S. Nat. Mus. 113: 605-635, 1962.
Includes very interesting table showing distribution of Clipperton species, and bringing out the island's strategic biogeographic location.

Howell, T. R.
Land birds from Clipperton Island.
Condor 61: 155-156, 1959.
Several species observed and 3 collected by Wayne Baldwin in 1956; all are species that breed in Eastern United States.

Lowry, G. M.
The Clipperton operation.
U. S. Naval Inst. Proc. 88(2): 170-171, 1962.
Account of the loss of LST 563 in Dec. 1944.

Sachet, M.-H.
Monographie physique et biologique de l'île Clipperton.
Ann. Inst. Océanogr. 40: 1-108, 1962.
Includes 12 plates of photos.

Urquizo, F. L.
El Capitan Arnaud.
1-107, Mexico, 1954.
Rather pathetic attempt at a biography of Capt. de Arnaud, and the the fate of the Mexican families abandoned on Clipperton in 1914. Hardly any new information, and no indication of sources.

Clipperton Island was in the news once more in Feb.-March 1962, when the San Diego tuna clipper M/V Monarch sank nearby, and the crew of 9 spent 23 days on the island (Feb. 6-March 1), awaiting rescue. Mr. W. L. Klawe, of the Inter-American Tropical Tuna Commission recently was able to interview Mr. Robert A. McCorckle, the navigator, and kindly put a tape-recording of their conversation at our disposal. From this, the notes of scientific interest have been summarized and are presented below; comments by the assistant editor are included in ( ). A narrative of the more dramatic aspects of the fishermen's adventure and rescue, together with some background information on Clipperton and the tuna fishing industry, has been accepted for publication by Argosy Magazine. We look forward to reading this account, and in the meantime, express our gratitude to the participants in the interview.

The Monarch sank at 9 a.m., and by 3 p.m., the crew had landed on shore after salvaging fishing lines, a box of fish hooks, some potatoes and a sack of onions from the sinking vessel. Shown the map of Clipperton included in ARB 86, Mr. McCorckle indicated the landing place as just north of the apron of deeper reef on the northwest side; from there they walked to the coconut grove. There was a slight sea, and landing through the "surf" (the breakers at the edge of the reef) offered difficulties, but there were capable oarsmen in the skiff, and they got ashore relatively easily. The large skiff in which they landed was lost over night, a smaller one, pulled higher on the beach, remained and turned out to be invaluable in that it permitted fishing in the ocean.

The quonsets of the old Weather Station in the coconut grove were found to be "in a state of collapse, of decay" so could not be used, but a shelter was built of old bags of cement, now solidified, and sheets of corrugated metal, and patched together with pieces of wood. It was adequate for the tropical climate.

Weather: Mr. McCorckle was a weather officer with the Air Force for 10 years, but felt a bit rusty on terminology. Visibility was at all times excellent. Cloud cover: sky condition "broken", middle and high clouds, cirrus, altocumulus, altostratus and stratus, with very few low clouds. Rainfall: it rained practically all night the first night, not a heavy rain of a storm type, but a "typical tropical rain" (meaning probably typical trade-wind rain). There was not "lots of rain", in fact, "for the tropics, very little rain." There were perhaps 6 nights out of 23 when it rained, and there was no rain during the day. (These observations are of extreme interest, in view of the total lack of weather data from Clipperton at that time of year. They confirm the idea expressed in ARB 86, pp. 20-21, table 3 and passim that there is a drier season in the first months of the year). Wind: The northeast trades never varied, except for slight fluctuations from NE to E or even occasionally to SE. There was nothing more westerly than NE or SE. There was surf (breakers) around the island all the time, even when it was calm. Humidity: "Humid, as it always is in the tropics, but the weather for February had far less rain than you would find elsewhere in the tropics." Temperature: The nights were cooler than the days, but still hot, probably not getting below 80°. Days quite warm, but not uncomfortably so (probably on account of the constant tradewinds). Fishermen are used to the sun, they were all

already quite brown, so nonesuffered from sunburn. In fact none was sick or had any complaint during the whole stay, except for one man whose foot was crushed between the skiff and the sinking vessel, and who has not yet really recovered.

Lagoon: Water was drinkable, but muddy and dirty; some men used it for drinking, but supply of drinking coconuts made it unncessary for the most part. It tasted not good, but apparently Mr. McCorckle did not find it noticeably salty. The water could have been used for cooking, but actually sea water was used. No fish was seen in the lagoon, but it was not looked for. The lagoon was full of floating plant growth, gathering near shore at times, as it moved with the wind. "I kept imagining that I could see the tide inside the lagoon ... Oh, I know there was" (a movement of the water inside the lagoon).

Vegetation: Asked whether the vegetation was dry or green, Mr. McCorckle said green.(Probably, the type of effect of the drier weather on the vegetation noted by Mr. Klawe in May 1958 (ARB 86, p. 21) had not made itself felt as yet. Similarly, the lagoon water had not yet become much saltier than during the rainy summer). The vines (Ipomoea pes-caprae), which to Mr. McCorckle's view formed most of the plant cover, were flowering "not abundantly but in patches." Shown the photos of the devastated north-east side (Monographie physique et biologique, 1962), he thought that area still devoid of vegetation (he did not walk all around the island, although others did, but the devastated area, if still bare, would be noticeable from the top of the ridge on the northwest side where they landed and later fished). Drift-wood was not obvious, but they did see some large stumps (when shown Allison's photo of a drift tree in the Monographie).

Food: There were all sizes of coconuts available; they were abundant, but when rescued, the fishermen were beginning to worry, as the supply was getting low. They got the nuts by climbing the shorter trees and by knocking the nuts off the taller ones with old pieces of pipe found in the old quonsets and with hooks attached. The quonsets also furnished all lumber for firewood. Potatoes and onions were boiled in sea water. Fish was boiled, or grilled on a piece of metal, as on a barbecue. They tried a few birds' eggs but found them "rancid and ready to hatch," so gave them up. They killed a few of the "little black birds" (noddies?) but decided they had too little meat on them. Mostly they fished. There were "few fish inside the breakwater" (on the reef flat) and they had to be speared, so it was much easier to fish in the open sea, with the small skiff. They caught only "cabrilla" (a grouper, Epinephelus), ranging from 8 to 20 pounds. For bait, they used "a longish fish, perhaps like an eel" found on the reef (probably moray eels, which are extremely abundant on the reef, although when asked if these fish tried to bite, Mr. McCorckle said no).

Marine life: In addition to the above, they saw when they were fishing in the open ocean some porpoises (probably black porpoises, Tursiops), schools of tuna, which of course they could not catch, no jack (Carangidae), no black skipjack (Scombridae), no seal or sea-lions, and no turtles. Occasionally a small shark could be seen inside the breakwater (on the

reef flat). There were quite a few lobsters on the reef (most likely Panulirus penicillatus), a few were caught at low tide; no shrimps were noticed. Many shells could be picked up on the beaches.

Land animals: (At the time of the rescue, the newspapers reported pigs on the island, but they must have extracted this information from their "morgues," as the fishermen saw only skeletons). Mr. McCorckle felt sure that there were no living pigs left. Birds: Mr. McCorckle is not especially familiar with birds, but mentioned Man o'war birds, albatrosses (boobies?) and gulls (terns?), and lots of little black birds (very likely noddies, but could be sooty terns). When shown the photos included in the Monographie, he recognized the fairy terns, of which there were a few, the boobies, of which there were lots, and the frigates, equally abundant. There were a few little lizards, very fast (obviously the skinks) , and no rats or mice. There were millions and millions of land crabs, annoying and inquisitive, but not bothersome (one wonders if the crabs have already increased as a result of the removal of the pigs in 1958, one would not then have described them as in millions and millions). They did not try to eat them. Of insects, only some flies and ants were noted, they were not bothersome. Centipedes were not noticed.

A bottle containing a message was picked up on the beach. It had been thrown overboard in the Panama canal (more likely in the Bay of Panama at Balboa) in Sept. 1960.

The crew of the Monarch was found on Feb. 27 by two small fishing boats, fishing for sharks. Their rescuers radioed another boat, located near Soccoro Island, Revillagigedo group, which in turn notified the Coast Guard, which alerted the Navy, which sent the destroyer U.S.S. Robison, then in El Salvador, to pick up the castaways.

Of these important pieces of information, the most valuable is no doubt that on the weather. The drier weather in the early part of the year was also confirmed from another source. Lt (now Commander) R. E. Kerr, who discovered and rescued in 1917 the Mexican women and children abandoned on Clipperton, kindly shared his vivid recollections of the episode with the assistant editor in an interview in August 1962. He remembers very clearly that Señora de Arnaud told him that they depended entirely on rain water for drinking purposes, which they collected in old boats (at that time there were only 6 coconut palms on the island), and that they used to worry about their depleting supply in the early spring. We are happy to be able to piece together such information, since the only "professional" weather data ever collected on the island, by the weather station of 1945, have never been available and are reported lost.

Marshall Islands:

It has just come to our attention that a revised edition of Atoll Research Bulletin No. 11, Land tenure in the Marshall Islands, was published in 1956. The revisions in this were extensive, the number of pages being increased from 36 to 67, with addition of much material of great interest. Although this purports to have been "Issued by the PACIFIC SCIENCE BOARD, National Research Council ... (Revised - June, 1956)", we have no knowledge of it, so cannot give any information on where it was issued nor how it can be secured. The editors do not even have a copy.

Laysan:

A paper by Richard E. Warner, entitled Recent history and ecology of the Laysan duck, is in press and will appear in 1963 in the journal Condor. A book on the natural history and ecology of Laysan Island, prepared jointly by members of the Harold J. Coolidge 1961 expedition to that island and under the editorship of Drs. Robert L. Usinger and A. Starker Leopold is in the last stages of preparation. It will appear as a technical publication of the University of California Press in 1963. An account of the expedition was presented by Dr. Miklos D.F. Udvardy in Elepaio 22(6): 43-47, Dec. 1961 (see also ARB 84, p. 1). ARB 79 reported some observations made on atolls other than Laysan during that expedition, and including notes on the invasion by weedy plants of recently disturbed islets of French Frigate Shoal and Kure. Richard E. Warner reports that, paralleling this invasion, changes in the fauna of Green Island, Kure, were observed. An astonishing number of newly introduced insects were found. There was an unconfirmed report of the presence of one species of snake on the island. It was also reported that the Hawaiian rat (Rattus hawaiiensis, or perhaps R. exulans?) a species apparently transported there by the early Hawaiians, had experienced a population eruption shortly after the arrival of military personnel. A vigorous poisoning campaign was instituted and at the time of the expedition's visit, only one dead and quite dried-up specimen was found.

Maldive Bibliography:

Mr. E. W. Groves, of the British Museum (Natural History) writes that he is compiling a bibliography on the Maldive, Laccadive, and Chagos archipelagoes, in the central Indian Ocean, groups entirely composed of atolls. We have, as yet, no information on where it will be published, but are awaiting its appearance with interest.

Cayo Arcas:

The reefs around Cayo Arcas, northwest of Yucatan, are being studied by the Department of Oceanography and Meteorology of Texas A. & M. College. During the past year the atoll has been visited by two expeditions, aboard the oceanographic vessel Hidalgo, under the direction of Dr. Louis S. Kornicker. Apparatus is being installed to measure current, tide, wave, and other energy components to try to relate them to reef growth. On the

second of these trips some work was done on shore, including the mapping of the vegetation by Mr. Max Pitcher, of Columbia University. Plant collections made by him were identified by F. R. Fosberg:

A. Sporobolus virginicus L.
B. Ipomoea tuba (Schlecht) G. Don
C. Amaranthus sp. (possibly A. greggi)
D. Tribulus cistoides L.
E. Sesuvium portulacastrum L.
F. Cyperus planifolius L.C. Rich.
G. Euphorbia mesembrianthemifolia Jacq.
H. Ipomoea stolonifera (Cyr.) Poir.?
I. Tournefortia gnaphalodes (L.) R.Br.
J. Ambrosia hispida Pursh
K. Suriana maritima L.
L. Cocos nucifera L. (not collected)
M. Scaevola plumieri (L.)L.
N. Hymenocallis littoralis (Jacq.) Salisb.?
O. Laguncularia racemosa Gaertn.
P. Philoxerus vermicularis (L.)R.Br.?
Q. Salicornia perennis Miller
R. Cakile lanceolata (Willd.)Schulz
S. Atriplex pentandra (Jacq.) Standl.
T. Portulaca oleracea L.
U. Opuntia cf. dillenii
V. Ricinus communis L.
W. Casuarina equisetifolia L.

So far as we know, there are no published records of plants from Arcas.

Jamaica:

A visit to the laboratory of Dr. Tom Goreau, of the University of the West Indies, Kingston, Jamaica, and a few days in the field with him on the Jamaica reefs and those of the Pedro Cays, gave a glimpse of some of the most interesting work now being done on certain phases of reef ecology. Work on the rates of carbonate deposition, and an attempt to get at the nature of this important phenomenon, form the central facet of the investigation. In addition, detailed reef profiles are being recorded by sonar apparatus. By far the most interesting aspect, however, is the opening up of a whole new reef biotope, in the deeper parts of the euphotic zone, down over the edge of the reef front and in the caverns that extend under the reefs, by means of diving with SCUBA gear. New organisms and new concepts of the distribution and abundance of many whole groups of marine animals and plants are resulting from this detailed examination, collecting, and photographing in a region only barely known previously from bits brought up by dredges. The first of a projected series of papers on this work appeared in Ecology 40: 67-90, 1959. In the work on the Pedro Cays, we had the help of the staff of the Institute of Jamaica, and especially of its director, Dr. C. Bernard Lewis, who also kindly shared with us his great fund of first-hand information and bibliographic knowledge of the Pedro Bank and Cays. For all this, we are very grateful.

Atolls off British Honduras:

As noted in the last News and Comments (ARB 84, p. 9), David Stoddart had hardly competed a detailed study of the sand cays and atolls off the coast of British Honduras (see ARB 87), when Hurricane Hattie, a storm of formidable intensity, swept across these cays on its way to devastate Belize. With the aid of the Office of Naval Research and the Royal Society, Mr. Stoddart was able to spend three months early in 1962 in British Honduras, restudying these cays, to determine what were the effects of the storm on them. Some of the changes were spectacular. He is

at present writing up his observations and we hope to be able to publish a companion to ARB 87 for comparison. A short account on Catastrophic storm effects on the British Honduras reefs and cays has been published in Nature 196(4854): 512-515, 10 November 1962. Mr. Stoddart has published a summary of the reef work of the Cambridge Expedition to British Honduras of 1959-60 in the general report of this expedition (Thorpe, J.E. and Stoddart, D.R., Geogr. Jour. 128: 158-173, 1962).

Dry Tortugas Keys:

A brief visit to the Dry Tortugas Keys, Fort Jefferson National Monument, in company with Bill Robertson, biologist of the Everglades National Park, resulted in a collection of the plants of the atoll and the realization that, in spite of the great amount of disturbance during more than 100 years of human occupation, there is much of interest to be learned there. Mr. Robertson has been observing the birds on his occasional visits; he has added significantly to Sprunt's list (A. Sprunt, Jr., A list of the birds of the Dry Tortugas, reprinted from the Florida Naturalist by the Florida Audubon Society, 1-27, 1951, with addenda); he is also keeping records of habits and behavior of birds, especially of the terns (see Auk 78: 423-425, 1961). He has collected specimens of the plants and observations on the vegetation and has promised a paper on Tortugas botany for the Bulletin. The National Park Service is to be commended for sponsoring this research; we also wish to thank the Service for making it possible to visit this American atoll.

Dr. H. K. Brooks, of the University of Florida, has carried out some studies of the bottom and reefs on the platform surrounding the Tortugas Keys, as well as taking some excellent under-water movies. He plans to continue these studies. It may be pointed out that this is a strategic place to study certain reef phenomena, as it is very near the temperature limits for active reef coral growth. Brooks has also started investigating the submerged reefs south of Appalachicola and west of Tampa, which are possibly just outside the present limits of reef growth.

Florida:

Other significant work on Florida reefs, of value for comparison with reefs and atolls in other regions of the world, is being carried out by Eugene Shinn. His beautifully illustrated report on Spur and groove formation on the Florida Reef Tract will appear in the Jour. of Sedimentology.

Recent Books

Atoll Environment and Ecology, by Herold J. Wiens:

Yale University Press, New Haven and London, 1962. 532 pp., 93 figures (including maps), 88 photographic plates, 407 references. $15. Reviewed by R. E. Warner, Berkeley, Calif.

With the Pacific Basin as his battlefield, author Wiens attacks the multifarious subject of atolls: their formations, physiographies, biotas, ecologies; and ends with a brief thrust at the human ecology of Pacific

Islands. The attack is vigorous, and broadly comprehensive. Writing for a wide range of readers, the author attempts to provide a "useful reference book for students and for administrators and naval personnel in the Pacific Islands"(p. xx).

It very quickly becomes apparent that the treatment is canalized; the perspective of the geographer being continually present. This indeed should not be unexpected, for Dr. Wiens is a capable geographer who candidly states in his preface,"within the framework of the purpose defined, I have included what I felt I would want to know were I newly assigned to live and work on or to study and enjoy the coral atolls"(p. xxi). Hence the treatment, with a few notable exceptions, is a broad overview; intriguing when dealing with subjects new to the reader, intensely frustrating when areas of special interest are cursorily examined then summarily dismissed from further consideration.

The physical, geological and climatological characteristics of atolls are explored in considerable detail, the first eight chapters (227 of 466 pages) being devoted to topics ranging from "Atoll shape" to "Theorizing on atoll origins." The preponderance of data seems to come from the Northern Marshall Islands, and regrettably little space is devoted to areas such as the leeward portion of the Hawaiian chain, where considerable scientific activity has been centered in recent years. Especially provocative are sections of Chapter 4, "The evolution of coral atolls: evidence and theory." Recent evidence obtained through drilling, seismographic and sonographic studies is providing progressively firmer ground for theoretical considerations of atoll formation. Shallow-water coral and calcareous algal deposits have been found to rest on basalt at a depth of 4,222 and 4,610 feet in two drill holes at Eniwetok. At Bikini the coral-basalt interphase was found at 2,556 feet (p. 92). The distribution and geological characteristics of guyots, those enigmatic flat-topped submarine mountains whose origin is still speculative, provide much food for thought, especially for the biogeographer. On p. 89 (fig. 38) a perspective view of the Pacific Basin in the Eniwetok-Rongerik area, taken from Von Arx's 1954 paper, clearly depicts a panorama of truncated high islands, now submerged to varying depths by isostatic adjustment, rise of sea level, and/or other unknown means. Nevertheless the author, perhaps wisely, refrains from drawing his own conclusions on this complex subject, ending his discussion with quotations from several relevant papers to the effect that "probably no single reef theory will explain all reefs."

Chapters 5 through 8 are devoted primarily to hydrological and climatological influences. The discussion ranges from "Sea-level changes" to "Typhoon frequency" and again is less an analysis than a general review of kinds of phenomena impinging on and contributing to the atoll environment. Statements relative to sea level changes, wherein the author leans heavily on the conclusions of Fairbridge (see pp. 107 and 134) are premature. The author, for instance, favors the view that as recently as 3,600 years ago a 10-foot-higher sea level probably submerged most present-day atoll land surfaces. This is not in accord with the degree of endemism found in the extant terrestrial biota of several low islands. Laysan Island, for example, would in all likelihood have been completely inundated by the proposed 10-foot rise in sea level. Yet the number of endemic

plants (7 of 26) and land birds (5 of 5) recorded in historic times strongly suggests a considerably longer period of emergence. At best, evidence for the 10-foot rise is tenuous.

The latter portion of the book is addressed to the biology of atolls. The treatment of each subject (e.g. Marine fauna dangerous to man, pp. 282-295; Atoll terrestrial fauna, pp. 404-449) is cursory. The beginning student will find it intriguing; the specialist, frustrating. Much available material has been neglected. Indeed, in some areas, important recent studies have been entirely omitted. In general the literature reviewed is restricted to animal-man and plant-man interactions. While this may be in keeping with the author's general goal, the student of atoll ecology will be disappointed in his search for fresh insights. It is in this latter portion of the book that the overextension in scope becomes most apparent. The "... dissection of the landscape and the physical and biological complex of the coral atoll in its tropical realm..."(p. xx), so heroically attempted, from the outset commits the author to the damnation of incompleteness. For the subject of atoll environment and ecology is too diverse, too ill-understood, and too widely scattered through the scientific literature to permit concise elucidation.

The administrator, the beginning student of Pacific Basin ecology, and the educated layman will find Atoll environment and ecology richly rewarding and full of new vistas of the Pacific world. The advanced student and the Pacific Basin specialist will be disturbed and often exasperated by its superficiality, its rather peculiar format, and the canalized treatment of subject areas; but should nevertheless find it a useful, if controversial, reference.

Bates, Marston, and Abbott, D. P., Ifaluk:

290 pp., Museum Press Ltd., 1960. We have not seen this book, but are told that it is slightly different from the authors' Coral Island (1958), and that the illustrations include some in color.

Ellice Islands:

It is good to see that old-fashioned ethnology, with its emphasis on material culture, has not been entirely supplanted by the more fashionable "functional" sort, that scarcely seems distinguishable from sociology except that it deals with less industrial societies. We have just received a copy of Die materielle Kultur der Ellice-Inseln, by Dr. Gerd Koch, 199 pp., published by the Museum für Völkerkunde, Berlin, 1961, which is a detailed and abundantly illustrated description of the things used by the Ellice Islanders in their everyday life. In addition to text on how each item is made, of what, how it is used, and what it is called, the author has presented careful drawings of most or all items. The work is based on nine months field work in the Ellice group in 1960-1961, and a study of available museum material. The drawings are supplemented by 23 plates of beautiful photos. We are not able to assess the technical details of this work, but it is safe to say that a study of this sort is greatly

to be desired for every island culture in the Pacific. The author has informed us that he will work in the Gilberts in 1963-1964. We hope he will have abundant support to continue this type of work indefinitely.

Maldives:

Unquestionably the most effective motivation for scientific research is a combination of a strong intellectual curiosity, a sense of wonder, and a keen appreciation of beauty. That Dr. Hans Hass is well endowed with all of these faculties is abundantly shown by his magnificently illustrated book on his last expedition, Expedition ins Unbekannte, published in Berlin, Frankfurt and Vienna in 1961. The expedition to the Maldive and Nicobar islands in the research vessel Xarifa (see ARB 70) concentrated on investigation of coral reefs and their fauna, and a number of scientific papers have been published on the results. The present book gives an account of the expedition itself, with much interesting information on the islands, the reefs, and their inhabitants, and a wealth of photographs, some in color. Also, there is a chapter outlining a new theory of coral reef formation, formulated by Dr. Hass, an English version of which is presented elsewhere in this issue. Included also (pp. 158-160) is a bibliography of the scientific publications resulting from the several Xarifa expeditions. Reading a book of this sort is the next best thing to participating in an expedition. We are eagerly awaiting the promised English translation so we can read it with less effort and enjoy it in comfortable laziness.

Indian Ocean:

"A partial bibliography of the Indian Ocean", compiled by A. E. Yentsch, has been published by Woods Hole Oceanographic Institution, financed by the National Science Foundation. This seems to be principally a compilation from other bibliographies rather than from the original literature, with the citations checked for accuracy if the original papers are in the library of the Marine Biological Laboratory at Woods Hole. It is a completely unannotated list, arranged by subject. The basis for selecting the subject categories as well as the papers to be listed in these categories is nowhere clarified, though there is little attention to anything above the intertidal zone except the weather. Botany is notably absent, except for references on phytoplankton and a section on macroscopic algae. Vertebrates are included, but there are no references on either birds or amphibians. Geography is not indicated either by cross-indexing or by any sectional arrangement. In the Biology section and its subdivisions, however, locations are indicated by headings at the right hand margin. The only index is to authors.

The section on Coral Reefs (Geology and Biology) and certain of the biology subdivisions will be useful to ARB readers, but they should keep in mind that the "partial" in the title is to be taken literally.

How the work may be procured and what is the price are nowhere indicated.

Matters of general interest

Polynesia:

Dr. Harald A. Rehder, of the U. S. National Museum is undertaking a survey of the marine mollusks of Polynesia, using this term in a biogeographical sense to include the triangular area the three points of which lie at Palmyra Island, the Cook Islands, and Easter Island. The major portion of the fieldwork for this study, which is largely supported by a grant from the National Science Foundation to the Smithsonian Institution, will be conducted on two trips in 1963, one early in the year, and the other during the summer and early fall.

The greater part of the time will be spent in making detailed studies and collections on various typical sections of reef and coastline on the following islands and atolls: Tahiti (Pare district) and Maupiti in the Society Islands, Vahitahi and Mangareva in the Tuamotus, Pitcairn, Henderson, and Ducie in the Pitcairn group, Hiva Oa and Nuku Hiva in the Marquesas, Raivavae and Rapa in the Austral group, Mangaia in the Southern Cook Islands, and Palmerston and Penrhyn in the Northern group of the Cooks.

These studies and collections will supplement those made in 1957 by Dr. Rehder on the principal islands of the Society group, and on Tikahau and Makatea in the Tuamotus, as well as by Dr. J.P.E. Morrison during a survey of Raroia Atoll in 1952, sponsored by the Pacific Science Board. In addition, all possible use will be made in the preparation of the report of collections from this area that can be located in other institutions or in private hands. It is hoped that a report can be presented that will give marine zoologists and biogeographers a clearer picture of the composition of the molluscan fauna of Polynesia, its relationship to the faunas of adjacent areas, and clues to its origin and past history.

Some field work will be carried out also on the non-marine faunas of Tahiti (Fautaua Valley), Maupiti, and Mangaia. From these collections it is hoped to determine what changes, if any, have occurred in the composition of the terrestrial snail fauna, comparing the present fauna with that given in the accounts of former collectors, such as Andrew Garrett, A. G. Mayor, and H. G. Crampton.

Mopelia:

Professor A. Guilcher, of the Institut de Géographie, University of Paris, is preparing a trip to Mopelia atoll, Society Islands, to study sedimentology, reef morphology and lagoon water, and has promised a note for a later issue of ARB, when the plans for this expedition are more advanced.

Cahiers du Pacifique:

No. 4 (June 1962) of this interesting journal has just been received. It includes an article on the crabs of French Polynesia, with a table of distribution of 186 species in 24 regions of the world, mostly tropical.

There is also an important news section, including references to recent reports, a section on the recommendations of the 10th Pacific Science Congress (Honolulu, 1961), information on recent conferences and expeditions, and a bibliography of recent papers on Pacific molluscs.

Rangiroa:

The coconut experiment station of the IRHO (Institut de Recherches pour les Huiles et Oléagineux) has been established and a small research program started. The Annual Report of IRHO for 1960 includes a note to this effect (p. 26) and a table of rainfall on Rangiroa Atoll, Tuamotus, the seat of the station.

Micronesia:

The Micronesian Reporter, a bi-monthly publication of the Headquarters of the Trust Territory of the Pacific Islands, reminds us, in the issue just received (vol. 10, no. 3, May-June 1962) that the Headquarters have recently been moved from Guam to Saipan. This issue includes the usual news and information, and an interesting article on Marshallese navigation.

Ellice Islands moving pictures:

A catalogue of scientific films has just been received from the Institut für wissenschaftlichen Film, Göttingen. It includes 13 movies made in the Ellice Islands by Dr. Gerd Koch (see also p. 14 of this ARB), on material culture (building a house, a canoe), dances, etc. For each movie, there is a booklet written by Dr. Koch, with illustrations and bibliography, introducing and describing the film.

Indian Ocean Expedition:

We fondly hoped that a modern investigation of the land and shore ecology of the Indian Ocean atolls could be undertaken in connection with the U. S. Biological Program of the International Indian Ocean Expedition, at least utilizing the ships for inter-island transportation and logistics. Encouraged to think this was possible, we expended serious efforts and much time into planning such an operation. Finally we were informed that there was no room on the vessels for any but oceanographers. Dr. D. D. Keck, of the National Science Foundation, sponsor of the Program, contributed the following announcement of the plans for the Biological Program:

"American biologists will participate in the International Indian Ocean Expedition by taking part in nine scheduled cruises of the Anton Bruun under the general supervision of the Woods Hole Oceanographic Institution, and on three cruises of the Te Vega, the biological vessel of the Hopkins Marine Station, Pacific Grove, California.

"The Anton Bruun is to accomodate the needs of 134 biologists, including 20 foreign scientists from 12 countries. Scientists have been selected by a panel on the basis of merit and the compatibility of their research programs with the opportunities that could be made for them. The ship's schedules are designed for wide coverage to get as much use as possible out of an expensive vessel. Consequently, it is not feasible to put shore parties on atolls and return a number of weeks later to take them off.

"The Te Vega will concentrate chiefly on island work. The scheduled cruises are now essentially subscribed. In connection with the Anton Bruun program, as many of the inshore scientists as possible are to be accomodated at Mandapam Camp, India, and Nosy Bé, Madagascar."

Reef Terminology Index:

The first circular inviting comment on and cooperation with a proposed index of reef terminology with definitions and usages was sent out in late 1956, although the idea was formulated much earlier. The response seemed enthusiastic and cooperation was promised by many people. The Office of Naval Research, on the basis of this, made a grant to support the clerical work and a small amount of compilation of the less obvious parts of reef literature. It was hoped that within two years ot so a first draft of the proposed index could be duplicated and circulated for comment. As things turned out, most of the promised cooperation did not materialize and several extensions of the period of the grant had to be requested. After five years it became obvious that this task could not be accomplished by volunteer help, so it was decided to use what remained of the grant to employ someone to do as much more compilation as possible, then to issue the results to date, even though incomplete. We were fortunate to find a graduate student in geology, Mrs. Mary Simon, who was interested in doing this, and who has been working during the past year on the project. It is necessary to close the compilation at the end of 1962 and to proceed at once with the editing and duplication of the several thousand definitions that have been extracted. It is hoped to issue this as a number of the Atoll Research Bulletin early in 1963. Any published definitions that any of our readers care to send in before the beginning of 1963 should be typed on 5 x 8 inch slips with exact references and sent either to the ARB editors or to Prof. Rhodes Fairbridge at Columbia University, New York, 27, N. Y.

Association for Tropical Biology:

At the Conference on Neotropical Botany, held at the Imperial College of Tropical Agriculture, St. Augustine, Trinidad, an Association for Tropical Biology was founded. Its aims are:

(a) to stimulate, encourage and support research in tropical biology;
(b) to promote the training and interchange of students, teachers and investigators in this field;
(c) the development of facilities to attain these objects.

Membership in the new Association is open to all those who are interested in tropical biology. The membership fee of $ 1 U. S. or its equivalent should be paid to Professor J. W. Purseglove, Imperial College of Tropical Agriculture, St. Augustine, Trinidad, West Indies. Members who join before December 31 1962 will be regarded as Founder Members of the Association.

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